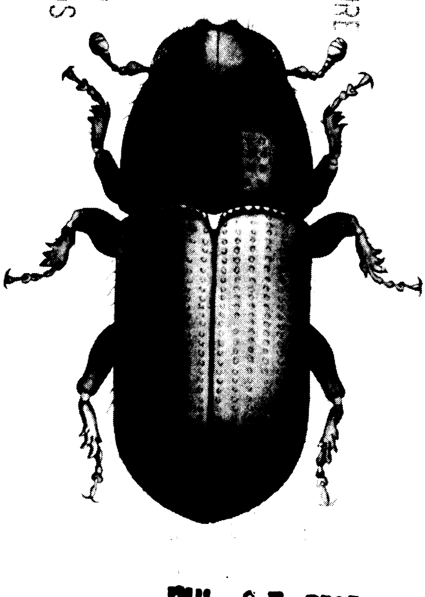
United States
Department of
Agriculture

Southern Pine Beetle Handbook

Combined Forest Pest
Research and
Development Program

Technical Bulletin
No. 1612

Site, Stand, and Host Characteristics of Southern Pine Beetle Infestations



Site, Stand, and Host Characteristics of Southern Pine Beetle Infestations

Jack E. Coster and
Janet L. Searcy, editors

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In 1974 the U.S. Department of Agriculture initiated the Combined Forest Pest Research and Development Program, an interagency effort that concentrated on the Douglas-fir tussock moth in the West, on the gypsy moth in the Northeast, and on the southern pine beetle in the South. The work reported in this publication was funded in whole or in part by the Program. This technical bulletin is one in a series on the southern pine beetle.

Contents

Introduction

The southern pine beetle (SPB), *Dendroctonus frontalis* Zimm., is a pest throughout the pine region of the southern United States. Following major outbreaks of the beetle in the early 1970's, the USDA launched a comprehensive research effort against the pest—the Expanded Southern Pine Beetle Research and Applications Program (ESPBRAP). One of the Program's principal objectives is to identify site, stand, and host conditions that are associated with SPB infestations. This information will serve as the basis for developing ways to rank susceptibility of stands to SPB attack. It will also provide clues for developing silvicultural recommendations to reduce beetle damage.

Seven different projects, sponsored by six agencies and covering seven States, cooperated under a coordinated regional proposal to collect a standard site/stand data set at each measurement plot. Geographic replication of the studies was considered essential since different factors were thought to predispose trees and stands to attack in different regions. Investigators involved in the Coordinated Regional Project were:

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R. R. Hicks, Jr., K. G. Watterston, J. E. Coster, and J. E. Howard. School of Forestry, Stephen F. Austin State University, Nacogdoches, Tex.

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R. J. Kushmaul, M. D. Cain, and W. F. Mann. Southern Forest Experiment Station, Pineville, La.

P. L. Lorio, Jr., and R. A. Sommers. Southern Forest Experiment Station, Pineville, La.

T. E. Maki, D. W. Hazel, and J. R. Hall. Department of Forestry, North Carolina University, Raleigh, N.C.

R. L. Porterfield and C. E. Rowell. Department of Forestry, Mississippi State University, Mississippi State, Miss.

J. M. Skelly, S. A. Alexander, and R. S. Webb. Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University, Blacksburg, Va.

This report presents the methodology and basic results from the Southwide projects. These results, from over 3,300 plots, should be valuable to future research on beetle-environment relationships and on basic silviculture, and to pest control specialists and forest managers as well. Hazard- or risk-rating models developed using the data reported here will be published elsewhere.

Study Methods

All participants collected certain data in a standardized manner so that results could be compared Southwide. Nearly all of the data presented were collected from 1974 to 1977. In addition, individual investigators acquired data for which they had special interest, knowledge, or facilities. Only the coordinated data, however, are reported herein.

The complete ESPBRAP Coordinated Site/Stand Project data set has been archived on computer tape. Researchers in forest entomology, silviculture, forest pathology, and soils may find the data useful. Information on its availability and location is in the Appendix.

Data Collection

Soil/Site Characteristics
At each infestation the soil/site characteristics were described using the *Soils Resource Guide, Southern Region* (USDA Forest Service 1972). This guide provides descriptive keys for use in the Mountain, Piedmont, and Coastal Plains subregions.

Two soil samples were collected at each location for laboratory analysis: one composite surface sample (0–15 cm) and another of the subsoil. The subsoil sample was taken at the midpoint of the B horizon. In the absence of a recognizable B horizon, investigators took a sample from the 60–90 cm depth.

Laboratory analyses of surface and subsoil samples included mechanical analysis by either the hydrometer or the pipette method, and pH by glass electrode in a 1:1 soil to water mixture.

Researchers estimated site quality by site index based on the height of loblolly pine (*Pinus taeda* L.) at base age 50. They determined tree age and total height on three to five dominant or codominant pines in the immediate vicinity of the infestation center for use with the Schumacher and Coile (1960) site index curves. Where possible, they selected these trees from each quadrant surrounding the infestation center, and included at least one infested and one uninfested tree. In addition, slope percent and aspect (azimuth) were recorded.

Stand Characteristics

Basal Area and Composition of Stand.—Basal area (BA) was determined with a 10 BA factor prism positioned at the center of the infested area. When a single tree represented the center, the prism was positioned 5 ft north. Field teams marked all "in" trees. Basal area was categorized as attributable to hardwoods or pine species.

Origin of Stand.—Stands were designated as plantation or natural (including artificially seeded areas).

Age.—Investigators determined the age of the stand from increment cores taken at breast height. Three to five trees were sampled in uneven-aged stands.

Stand Disturbances.—Plot disturbances that appeared to have occurred within the past 5 years were noted and categorized as follows:

1. No known disturbances
2. Logging activity within previous year
3. Logging activity 1 to 5 years ago
4. Ice and/or hail damage, severe—over one-half of stems affected
5. Ice and/or hail damage, light—less than one-half of stems affected
6. Fire within previous year
7. Fire 1 to 5 years ago
8. Lightning strike evident
9. Chemical brush control within previous year
10. Chemical brush control 1 to 5 years ago
11. Wind damage

Stand Understory.—An estimation was made of the percent occupation of the site by woody understory vegetation that was not included in the BA assessment. Field teams made this estimation visually by vertically projecting understory crowns to the ground and estimating occupation to the nearest 10 percent.

Size of Infestation.—Total number of SPB-infested (dead or dying) trees in the infestation was tallied. Estimated size of infested area was recorded in 1/4-acre increments.

Stand Diameter.—The average diameter at breast height (d.b.h.) and the range in d.b.h. of those trees counted as "in" the BA plot was determined.

Stand Density.—The number of trees per acre was obtained from d.b.h. measurements taken (Avery 1967).

Tree Characteristics

The following characteristics were recorded for each individual "in" pine tree on the BA plot.

1. Species
2. Status
   a. Live (uninfested)
   b. Dead (SPB-infested)
   c. Dead (unknown causes)
3. Disease incidence based on visible evidence of
   a. *Cronartium fusiforme* (bole galls)
   b. *Fomes annosus* (conks or windthrown trees with stringy roots)
4. D.b.h. to nearest 0.1 inch
5. Total height to nearest foot
6. Height to live crown to nearest foot
7. Bark thickness measurements on site index trees for maximum thickness (from the ridges) and minimum thickness (from the base of the fissures). Measurements were taken to the nearest 0.1 inch at breast height.
8. Radial growth measurements of site index trees from increment cores at breast height. The radial growth in millimeters was determined for each of the last two 5-year periods.

Plot Selection Criteria

From aerial and ground surveys researchers randomly selected SPB infestations. The center point of each plot was established at or near the oldest infested pine. Field teams determined this point by assessing foliage color of the attacked tree, loss of needles, bark sloughing, and the occurrence of probable causative disturbance factors such as lightning strikes, logging damage, and other activities.

Nearly all plots were taken in infestations less than 3 months old, and no plots were selected from infestations more than 1 year old. The percent of total SPB infestations sampled in an area varied by project and year, but in all cases the sampled infestations taken can be considered representative of all infestations for the respective areas.

Gulf Coastal Plain

Basis for Comparison

A complete and detailed description of SPB infestations by region and Southwide is very useful. Such a description characterizes the type of sites and stands in which SPB attacks are most likely to occur. One question arises immediately, though: How much different are the infestations from unattacked stands? The forest manager must have some idea of the magnitude of these differences in order to determine priorities for stand treatment. Some assessment of unattacked stand conditions is therefore needed.

Two types of unattacked plot data were used in order to characterize unattacked stands. "Control" plots were established near the infestations. These plots were used to determine if differences between attacked and unattacked stands were due to microsite variation within the stand. That is, whether intrastand variability accounted for the major component of SPB susceptibility. The second type of unattacked data was obtained from "baseline" plots established randomly or in line-grid fashion across the individual study areas in order to characterize general forest conditions in each area. Typically, control plots were intermediate with regard to site/stand characteristics between SPB-attacked and baseline plots. Since the forest resource manager most commonly deals with entire stands as to susceptibility rather than intrastand or microenvironment effects, the baseline plots are the preferred standard for comparison.

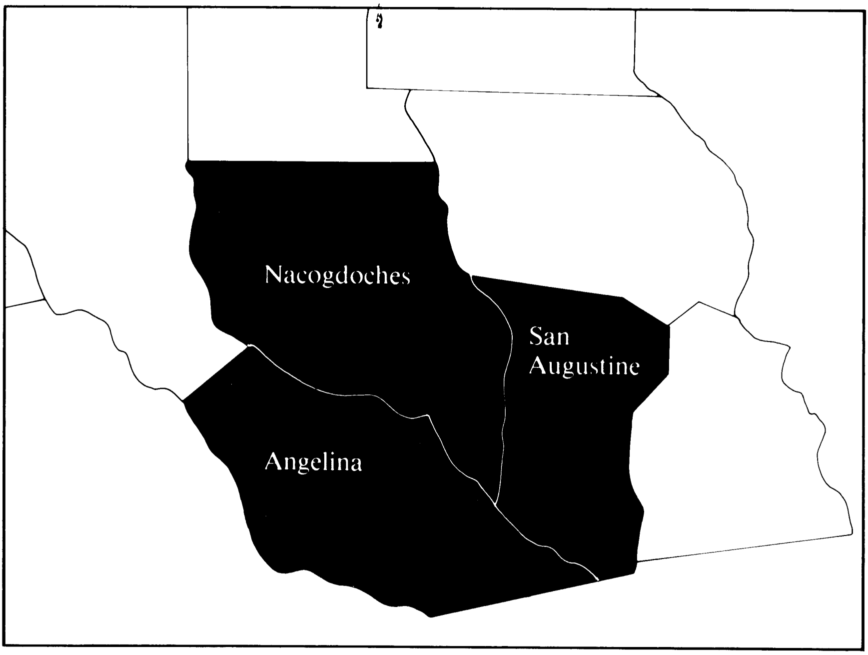
Eastern Texas

Ray R. Hicks, Jr., Kenneth G. Watterston, Jack E. Coster, and James E. Howard

Study Area

The study area encompasses Nacogdoches, Angelina, and San Augustine Counties in east Texas (fig. 1), with a total area of 1.56 million acres, of which approximately 1 million acres are forested (Earles 1976). This land is part of the West Gulf Coastal Plains subregion. The major topographic features are low, rolling hills and upland flats, dissected by broad valleys and flood plains and ranging in elevation from 120 to 300 ft above sea level.

The forest is part of the "east Texas pineywoods" and is near the western limit of the contiguous range of southern pines. The principal tree species on upland sites include loblolly pine and shortleaf pine (*Pinus echinata* Mill.), with various mixtures of hardwoods. Hardwoods such as sweetgum (*Liquidambar styraciflua* L.) bottomland oaks (*Quercus* spp.), and hickories (*Carya* spp.) predominate in first bottoms, with baldcypress (*Taxodium distichum* [L.] Rich.) occurring along sloughs and streams. Loblolly pine may become a significant component of forests on second bottoms and natural levees.



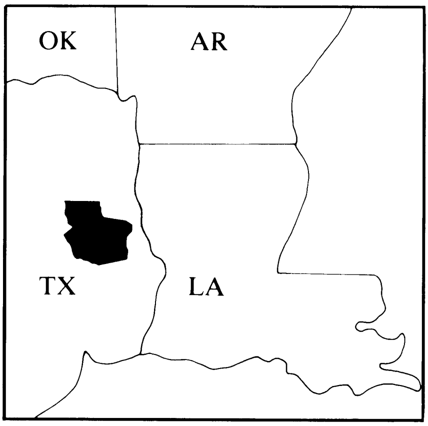


Figure 1.—Three-county study
area in east Texas.

Table 1.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—eastern Texas Coastal Plain

Variable
Slope*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
Avg. d.b.h. (''in'' trees)
SPB-killed trees
Spot size
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago

*Mean and standard deviation for those plots with non-zero slope. Seventy-one percent of the attacked stands and 56 percent of the unattacked stands had no slope.

Units	Attacked plots (252)		Baseline plots (386)	
	Mean	SD	Mean	SD
%	11.0	8.3	13.3	9.2
%	68.7	15.0	69.2	15.1
%	22.4	10.6	22.2	11.2
%	8.8	8.6	8.5	7.1
$\log \frac{1}{[H^+]}$	5.1	0.6	5.1	0.6
cm	43.3	29.4	47.6	31.5
%	50.9	16.9	50.4	18.5
%	21.5	9.3	20.5	9.8
%	27.6	15.7	29.0	15.8
$\log \frac{1}{[H^+]}$	4.8	0.7	4.7	0.7
ft^2/acre	122	40.4	76	41.3
ft^2/acre	22	20.9	32	27.7
ft^2/acre	143	38.6	109	39.6
%	57	25.6	46	25.6
years	41	14.3	40	14.1
trees/acre	617	423.4	732	871.9
ft	76.8	13.0	75.8	12.0
in	10.1	2.3	10.4	2.8
number	63.2	97.7	0	0
acres	0.6	0.9	0	0
in	0.2	0.1	0.1	0.6
in	1.0	0.3	0.9	0.2
mm	13.9	5.6	17.6	7.3
mm	15.9	7.5	18.7	8.0

Upland forest types in the study area constitute the primary host types for SPB. Pine and pine-hardwood types cover about 85 percent of the forested portion of the study area.

The two largest ownership classes for forest land in the area are forest industry (about 44 percent) and nonindustrial private owners (about 45 percent). The remainder is split between U.S. Forest Service (approximately 11 percent) and other public owners (Earles 1976). The study area includes parts of three National Forests (Angelina, Sabine, and Davy Crockett).

SPB activity has historically been high in east Texas, with the greatest activity centered about 50 miles south of the study area. During the study (1975–77), an epidemic beetle population existed: the Texas Forest Service reported roughly 20,000 infestations in the area from 1974 to 1976.

Surveillance reports from the Texas Forest Service helped us locate beetle infestations. During 1975 and 1976, the infestations to be sampled were chosen in a random manner. But it became apparent that beetle activity was not uniform over the area, so the 1977 plots were allocated to insure collection of a representative sample.

The noninfested samples in this study are properly described as baseline plots, the purpose of which is to characterize the forest conditions in the area. Prior to 1977, we located plots in an unbiased manner so that each 5 × 5-mile grid square in the study area contained at least two plots. In the poststratification process implemented in 1977, additional baseline plots were located in grid squares proportionate to the host-type forest land within the squares. Researchers collected 548 baseline plots, which was determined to be an adequate number to characterize the area (Bozeman 1977).

Results and Discussion

Characteristically, SPB-infested stands were located on flatter slopes than uninfested stands (table 1). Compared to the baseline plots, attacked plots were more heavily stocked and had a higher proportion of pines. Radial growth during the most recent 5-year interval was considerably less for the attacked plots, reflecting the more intense competition in such stands. Thus table 1 demonstrates that both site and stand factors leading to reduced growth and vigor are involved in predisposing trees to beetle attack.

Table 2.—Landform classification of attacked and baseline plots in natural, undisturbed stands—eastern Texas Coastal Plain

Landform	Attacked (252)	Baseline (386)
	Percent	
1. Flood plain	6.7	4.9
2. Stream terrace	2.0	2.1
3. Bay	2.8	1.0
4. Upland flat	55.6	41.7
5. Lower slope	8.7	9.3
6. Side slope	19.0	26.7
7. Steep side slope	1.2	2.6
8. Ridge	3.2	11.4
9. Other	0.8	0.3
	100.0	100.0

Beetle infestations occurred at a higher-than-expected frequency on low-lying landforms such as flood plains, stream terraces, bays, and lower slopes (table 2). These landforms had a combined frequency of 20.2 percent for infested and 17.3 percent for baseline plots. Most attacked and baseline plots occurred on upland flats (56 percent and 42 percent, respectively). The higher uplands and sloping sites (perhaps drier sites) had a lower-than-expected attack rate. The combined percent of attacked plots on side slopes, steep side slopes, and ridges was 23.4 percent for attacked and 40.7 percent for unattacked stands.

*Table 3.—Disturbance categories of attacked and baseline plots—eastern Texas Coastal Plain**

Disturbance	Attacked (561)	Baseline (548)
	Percent	
1. No known disturbance	45	70
2. Logging activity within previous yr	8	6
3. Logging activity more than 1 yr ago	6	17
4. Ice and/or hail damage, severe—over one-half of stems affected	0	0
5. Ice and/or hail damage, light—less than one-half of stems affected	0	1
6. Fire within previous yr	1	1
7. Fire more than 1 yr ago	3	4
8. Lightning strike evident	32	1
9. Chem. brush control within previous yr	0	0
10. Chem. brush control more than 1 yr ago	0	0
11. Wind damage	5	0
12. Other	0	0
	100	100

*A plot may have more than one disturbance.

Disturbances apparently triggered many infestations (table 3). Lightning strikes occurred at 32 percent of the infestations, while only 1 percent of the baseline plots showed this damage. Logging activity within the previous year represented the next most common stand disturbance. About 8 percent of the attacked plots had been disturbed by logging, while this phenomenon was recorded in only 6 percent of the baseline plots. Other disturbances were negligible for both attacked and baseline plots except that about 17 percent of the baseline plots showed evidence of logging more than 1 year before sampling, compared to 6 percent of attacked plots (table 3).

Table 1 shows that the average pine BA per acre is much greater for attacked plots. Table 4 shows that the distribution of BA also differs for the two stand categories. A definite positive shift in the total BA distribution can be seen for attacked plots. Sixteen percent of the attacked plots had BA less than 100 ft^2/acre, while 50.2 percent of the baseline plots were within this range. Conversely, 58.8 percent of the attacked plots had BA exceeding 130 ft^2/acre, as compared to only 21 percent for the baseline

Table 4.—Basal area class (combined pine and hardwood) of attacked and baseline plots in natural, undisturbed stands—eastern Texas Coastal Plain

Basal area class	**Attacked (252)**	**Baseline (386)**
ft^2/acre	Percent	
<50	0.4	4.1
50–70	2.8	15.8
80–100	13.1	30.3
110–130	25.0	28.8
140–160	31.7	10.6
170–190	18.7	8.0
200–220	6.0	1.8
230–250	2.0	0.3
≧ 260	0.4	0.3
Average BA (ft^2/acre)	143	109
Average percent pine	84	70

Table 5.—Size and frequency distribution of infestations in natural, undisturbed stands—eastern Texas Coastal Plain (n = 252)

Acres (nearest 0.25 acre) Lower limit	Upper limit	**Percent of total**
0	0.25	59.1
0.5	1.0	32.1
1.25	2.0	6.0
2.25	10.0	2.8
10.25	20.0	0
20.25	50.0	0
50.25	+	0

plots. Most of the infestations were small; 59.1 percent were less than 1/4 acre (table 5).

In conclusion, it appears that about one-third of the infestations in eastern Texas were induced by disturbances such as lightning or logging damage that were unrelated to the presence of site, stand, or host characteristics. The remaining spots were associated mainly with wet, low-lying sites and with overstocked stands. The susceptibility of east Texas pine stands is, thus, determined by several predisposing factors; the degree of susceptibility depends on the number and level of these factors (Hicks et al. 1978b).

Southern Arkansas

Timothy T. Ku, James M. Sweeney, and Victor B. Shelburne

Study Area

Though SPB outbreaks historically have been rare in Arkansas, an outbreak began in 1969 in the southeast corner of the State and spread toward the northwest. At the peak of the epidemic, in 1977, SPB infestations occurred in 24 counties in south Arkansas (fig. 2). Data collection began in April 1975 and was concentrated in the southeast sector of the State; it followed the progress of the epidemic.

South Arkansas is characterized physiographically as Upper Gulf Coastal Plain. The soils are generally loamy in nature, and loblolly and shortleaf are the two native pine species. Shortleaf pine becomes dominant in the northern and western sections of the State. Most of the pine stands are natural in origin. The ownership is made up of many small, nonindustrial landowners and a few large industrial owners. This study includes all ownership types and represents a cross section of beetle-attacked areas rather than a concentration in a particular management type.

Additional Procedures

A preliminary analysis of 743 attacked plots and all control plots collected until June 1976 indicated that stand disturbance was significantly related to beetle attack. However, the data also suggested that undisturbed plots might be more indicative of inherent site and stand conditions that predispose an area to attack because of their larger area of infestation and greater number of trees killed. Therefore, data collection was redirected to SPB infestations showing no signs of disturbance. This stratification resulted in 230 natural, undisturbed plots on the Coastal Plain. This stratification was not extended to baseline plots collected from June 1976 to March 1977. These plots were established in the southwest corner of every township of the SPB-infested area.

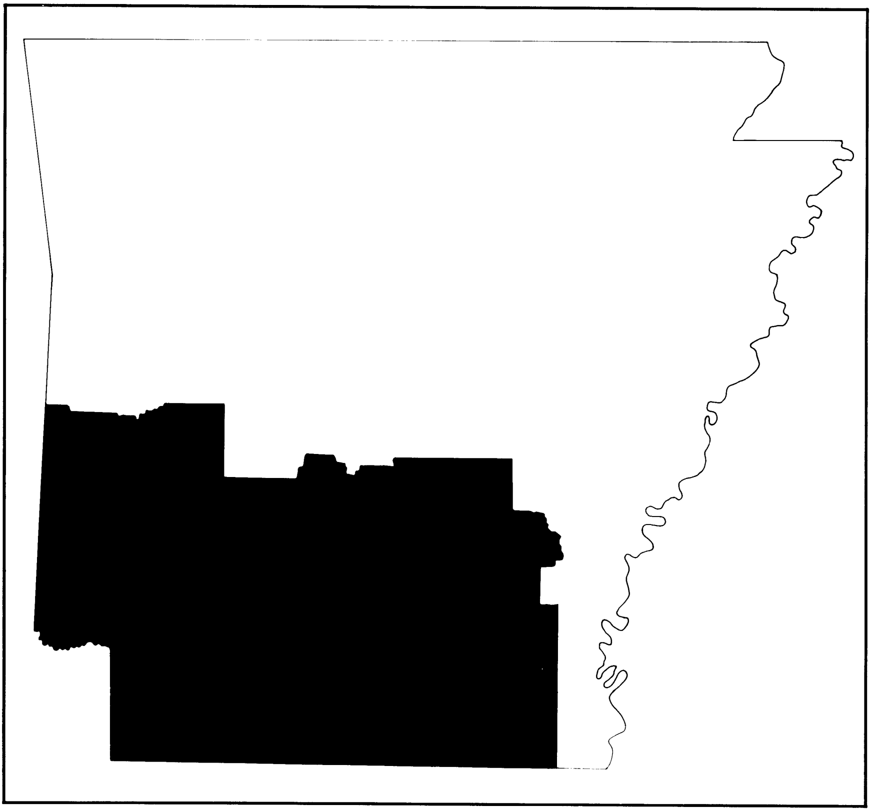


Figure 2.—Study area in southern Arkansas.

Results and Discussion

The natural, undisturbed, attacked plots in Arkansas are younger, exhibit slower radial growth and thinner bark, and have a higher proportion of pine than baseline plots (table 6). The former also exhibit higher average BA/acre and occur more frequently in stands with high BA than in baseline plots (table 6).

Table 6.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—southern Arkansas Coastal Plain

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago

*Mean and standard deviation for those plots with nonzero slope and aspect. Fifty-five percent of the attacked plots and 30 percent of the baseline plots had no slope.

Units	Attacked plots (230)		Baseline plots (115)	
	Mean	SD	Mean	SD
%	5.9	11.7	7.5	5.6
degree	182.0	112.0	175.0	110.0
%	53.8	17.6	52.0	20.0
%	36.1	15.1	37.0	17.0
%	10.1	5.9	11.0	9.0
$\log \frac{1}{[H^+]}$	5.3	0.4	5.2	0.4
cm	30.0	20.2	36.4	25.4
%	44.6	16.9	45.0	18.0
%	33.7	13.7	33.0	15.0
%	21.7	12.3	22.0	13.0
$\log \frac{1}{[H^+]}$	5.2	0.4	5.2	0.4
ft^2/acre	106	46.7	75	38.8
ft^2/acre	22	24.6	32	30.0
ft^2/acre	128	45.5	107	39.0
%	43	70.4	39	32.0
years	32	15.4	36	14.0
trees/acre	905	1262.5	903	1444.0
ft	79.1	11.0	79.0	11.0
number	66.7	155.8		
in	0.3	0.2	0.3	0.1
in	0.7	0.3	0.8	0.2
mm	17.9	6.6	19.2	7.0
mm	19.2	9.4	21.0	

Table 7.—Landform classification of attacked and baseline plots in natural, undisturbed stands—southern Arkansas Coastal Plain

Landform	Attacked (230)	Baseline (115)
	Percent	
1. Flood plain	4.9	6.1
2. Stream terrace	2.7	5.2
3. Bay	0.0	0.9
4. Upland flat	79.4	60.0
5. Lower slope	0.4	1.7
6. Side slope	9.0	24.3
7. Steep side slope	0.4	0.9
8. Ridge	3.1	0.9

The distribution of plots in the landform classes indicates that more attacked plots occurred on upland flats, the most common landform type in the study area (table 7).

Table 8 depicts the occurrence of disturbance in the initial 678 natural infested plots (not all plots are used in this comparison due to the sampling stratification) and natural baseline plots. Only 17 percent of the attacked plots are undisturbed, as opposed to 56 percent of the baseline plots. χ^2 analysis on the frequency of disturbance showed that beetle infestation is significantly related to disturbance ($P = 0.01$). Lightning strikes and recent logging activity appear to be the most detrimental forms of disturbance, followed by ice damage and recent chemical brush control. Past logging activity and past chemical brush control are not as important. Prescribed fire appears to have no relation to SPB attack. Nearly 80 percent of all southern Arkansas infestations were 1/4 acre or less in size (table 9).

*Table 8.—Disturbance categories of attacked and baseline plots—southern Arkansas Coastal Plain**

Disturbance	Attacked (678)	Baseline (206)
	Percent	
1. No known disturbance	17.0	56.0
2. Logging activity within previous yr	19.0	8.0
3. Logging activity more than 1 yr ago	25.0	21.0
4. Ice and/or hail damage, severe—over one-half of stems affected	4.0	4.0
5. Ice and/or hail damage, light—less than one-half of stems affected	20.0	8.0
6. Fire within previous yr	0.7	0.4
7. Fires more than 1 yr ago	1.4	3.0
8. Lightning strike evident	39.0	0.4
9. Chem. brush control within previous yr	2.5	0.0
10. Chem. brush control more than 1 yr ago	3.8	2.0
11. Wind damage	1.0	0.4
12. Other	3.5	6.3

*A plot may have more than one disturbance.

Table 9.—Size and frequency distribution of infestations in disturbed and undisturbed plots—southern Arkansas Coastal Plain (n = 973)

Acres (nearest 0.25 ac)		Percent of total
Lower limit	Upper limit	
0.0	0.25	78.7
0.5	1.0	14.2
1.25	2.0	3.8
2.25	10.0	3.4
10.25	20.0	0.0
20.25	50.0	0.0
50.25	+	0.0

Table 10.—Basal area class of attacked and baseline plots in natural, undisturbed stands—southern Arkansas Coastal Plain

Basal area class	**Attacked (230)**	**Baseline (115)**
ft^2/acre	Percent	
< 50	1.3	5.2
50–70	10.8	14.8
80–100	18.8	36.5
110–130	25.6	24.3
140–160	22.9	11.3
170–190	11.7	5.2
200–220	6.7	2.6
230–250	0.9	0.0
≧ 260	1.3	0.0
Average BA in ft^2/acre	128.4	106.6
Average percent pine	82.8	70.2

Table 10 shows that attacked plots had higher basal areas. Eighty-five percent of baseline plots had BA < 130 ft^2/acre, whereas only 56 percent of the attacked plots had BA < 130 ft^2/acre.

Because both loblolly and shortleaf pines were present in the plots, a test was done to determine whether one species was more susceptible than the other. χ^2 tests of SPB-attacked trees *v.* healthy trees for each species within all infested plots indicated that shortleaf pine was attacked more often than loblolly pine (P = 0.01). The same test was run on undisturbed plots; again shortleaf pine was attacked more often (P = 0.01).

In summary, the data indicate that while disturbance may indeed predispose a stand to attack, inherent stand conditions probably lead to larger and more devastating infestations. The lack of practical differences in site variables may be due to their interactions and resultant complexities. The high BA found in the undisturbed infested stands appears to be the major factor that causes competition, weakens the stand, and results in increased susceptibility to SPB attack. The slower growth may be merely an indicator of this competition.

Central Louisiana

Peter L. Lorio, Jr., and
Robert A. Sommers

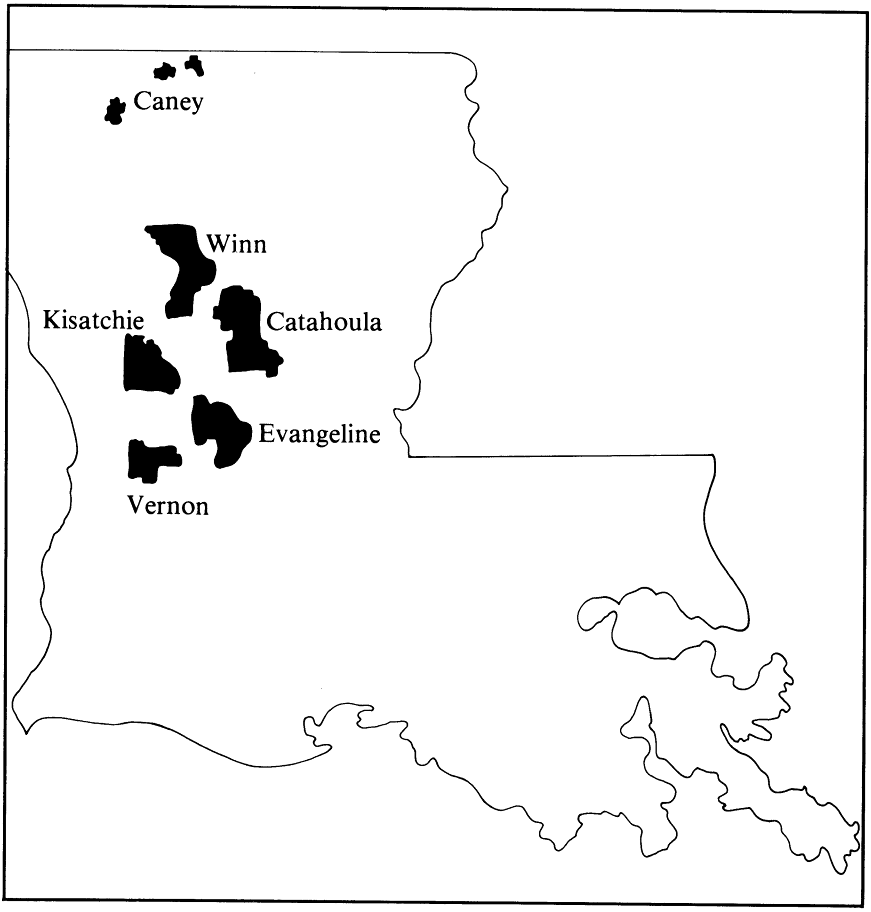


Figure 3.—Study area on Kisatchie National Forest in central Louisiana.

Study Area

The 560,000 acres of commercial forest land included in the Kisatchie National Forest, in central Louisiana, represent a good cross section of pine sites in the Louisiana Upper Coastal Plain (fig. 3). This forest and the data base associated with its management provided an excellent opportunity to study SPB site and stand relationships.

The Kisatchie timber management plan (FY 1972 through 1981, updated 8/28/78) describes the forest as about 90 percent pine and hardwood-pine types. Loblolly pine predominates, but shortleaf, longleaf (*P. palustris* Mill.), and slash pine (*P. elliottii* Engelm. var. *elliottii*) occupy considerable acreage. The forest is mostly middle-aged: 34 percent in age class 35 and below, 64 percent over 35, and 3 percent unclassified. Rotation age for the Yellow Pine Working Group (loblolly, slash, and shortleaf) is 60 years, and the prevailing site index at age 50 is 88 (ranging from 70 to 120). Rotation age for longleaf is 80 years and site index is 80 (range 70–100).

Additional Procedures

This study varied somewhat from the other ESPBRAP site/stand projects in that it assessed all SPB infestations within the National Forest study area and sampled a portion of them. Continuous Inventory of Stand Conditions (CISC) provided baseline data for the study.[1] We recorded pertinent information for each infestation from the appropriate compartment prescription summary sheets maintained by the National Forest. Data included forest type, stand condition class, site index, and age. Criteria for forest type are those of the Society of American Foresters. The primary factors considered in stand condition class are damage, quality, density, and age. Definitions are given in the *Silvicultural Practices Handbook* (USDA Forest Service, FSH 2471.1-R8, Sept. 1974). Site index (Schumacher and Coile 1960) is reported by 10-ft classes, and age by year of stand establishment. Such data were recorded for all infestations, but plots were established only in infestations with five or more infested trees, and preferentially without disturbance.

We report data from two types of plots. First, data from single-point, 10 BA factor prism plots were collected and summarized as in the other Coordinated Regional Projects. This single-point plot served as the starting point for the second plot type, a hexagonal cluster of 10 sample points (fig. 4). The single-point, 10 BA factor plot served as point 1 in the cluster plot. The cluster plots were established to get an even distribution over approximately 1 acre with points far enough apart to be reasonably independent (USDA Forest Service 1972). The central four points (1, 2, 5, and 9) represented the infestation origin; the outer six points represented either uninfested or subsequently infested sites; however, these sites are not comparable to control or baseline plots as reported in the other projects.

The use of cluster plots provides more extensive sampling of SPB-infested stands than that possible with single-point plots. At each point in a cluster data were recorded for all pines $\geqq$ 5.0 inches

[1]CISC is an automatic data processing system that reflects a continuously updated description of timber stands.

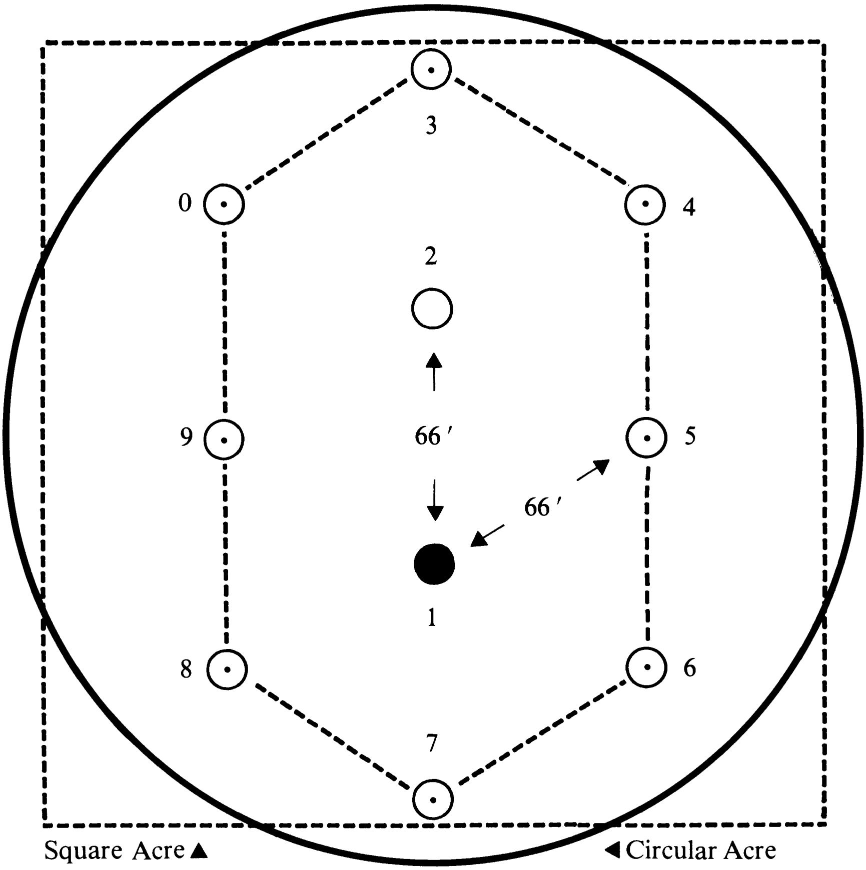


Figure 4.—Plot design for study of SPB infestations; point 1 is the location of the single-point plot (after *Forest Resources Inventory Work Plan,* U.S. For. Serv., South. For. Exp. Stn., New Orleans, La. Unpublished work plan).

Area within dashed line connecting 10 points of cluster equals 0.43 acres.

d.b.h. that fell within the limiting distance of 37.5 BA factor prism. Only BA was recorded for hardwoods.

Data from the cluster plots were summarized by a computer program specifically written for this study.[2] Summary data for each point included BA/acre of pine and hardwood, the number of pines per acre, and d.b.h., total height, and live crown ratio of the pine of average BA. The summary program produces a card output that may be used to calculate current volume and to protect yield with program YLDTBL (Myers 1977).

Results and Discussion

Single-Point Prism Plots.—A total of 1,679 SPB infestations occurred on the study area during the 25-month study period, from June 1975 through June 1977. Of these, 324 were sampled with 10-point cluster plots. Table 11 summarizes data from point 1 of 223 of the cluster plots that were established in natural, undisturbed stands. These 10 BA factor prism plots constitute the basic data for the Coordinated Regional Project.

Gently sloping sites with southerly aspect prevailed among all infestations. Soil texture averaged sandy loam in the surface and loam in the subsoil, with an especially wide range of subsoil textures represented (figs. 5 and 6). Soils were predominantly very strongly acid in both the surface and subsoil. Both the textural and soil reaction characteristics are representative of pine forests in the West Gulf Coastal Plain; no special relationship between SPB infestations and these site variables exists. Average surface soil depth of 42 cm (17 in) and loblolly pine site index of 96 ft, as well as the data on slope and soil texture, indicate that infestations in natural, undisturbed stands were on productive pine sites.

Data in table 11 on age, bark thickness, and radial growth were limited to 931 trees purposely selected from the dominant stand for site index estimates. These trees averaged 16.1 inches d.b.h.

Infested stands averaged 77 percent pine, 142 ft^2 of total BA, and 39 SPB-killed trees. The diameter of the tree of average BA, including hardwoods, was 6.2 inches; this figure reflects the numerous small-diameter trees included in plot sampling. Stands averaged about 50 percent understory cover of vegetation not included in the prism plot.

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[2]Program written by Clifford A. Myers, Southern Forest Experiment Station, retired.

Table 11.—Site and stand characteristics of attacked plots in natural, undisturbed stands—Kisatchie National Forest

Variable	Units	Attacked (223) Mean	SD
Slope*	%	3.3	3.1
Aspect*	degree	187.0	107.0
Surface sand	%	58.9	15.8
Surface silt	%	31.2	13.4
Surface clay	%	9.9	6.5
Surface pH	$\log \frac{1}{[H^+]}$	4.9	0.3
Surface soil depth	cm	41.5	20.1
Subsoil sand	%	42.9	18.6
Subsoil silt	%	31.3	13.5
Subsoil clay	%	25.8	13.8
Subsoil pH	$\log \frac{1}{[H^+]}$	4.8	0.3
Pine BA	ft^2/acre	109	4.4
Hdwd. BA	ft^2/acre	32	2.7
Total BA	ft^2/acre	142	4.8
Stand understory	%	52	23.7
Age	years	42	14.9
Density	trees/acre	676	938.4
Site index at 50 yrs	ft	95.5	11.8
SPB-killed trees	number	38.8	59.4
Avg. bark—fissure	in	0.2	0.6
Avg. bark—ridge	in	1.1	0.2
Avg. radial growth 0–5 yrs ago	mm	14.6	5.3
Avg. radial growth 6–10 yrs ago	mm	15.3	5.8

*Mean and standard deviation for those plots with nonzero slope and aspect. Twenty-six percent of the stands had no slope.

Table 12.—Landform classification of attacked plots—Kisatchie National Forest

Landform	Natural undisturbed (223)	All infestations (1,679)
	Percent	
0. Swamp	0.0	1.9
1. Flood plain	13.1	12.3
2. Stream terrace	8.1	10.8
3. Bay	0.0	0.0
4. Upland flat	11.7	12.2
5. Lower slope	15.7	11.0
6. Side slope	0.9	3.1
7. Steep side slope	0.4	0.5
8. Ridge	39.0	37.1
9. Low ridge	10.3	11.1
	100.0	100.0

The frequency distribution of landforms for plots in natural, undisturbed stands was very similar to that for all recorded infestations (table 12). Ridge was the landform most often reported. Many of the so-called ridges probably more closely resemble upland flats—nearly level or slightly concave areas on interstream divides, characterized by slow surface and internal water movement. Also, based on laboratory analyses, loamy and medium-textured soils may have been more frequently associated with infestations than field observations suggest (figs. 5 and 6). Mapping unit codes 42200 and 44200 describe such sites. These mapping unit codes correspond to the high loblolly pine site index reported in table 11.

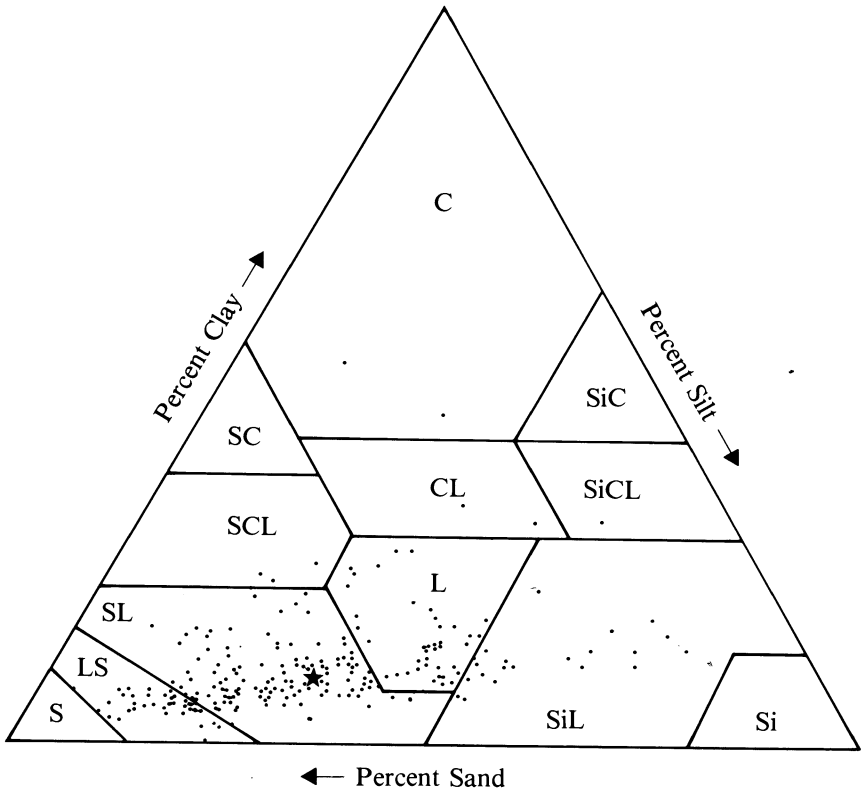


Figure 5.—Distribution of 223 surface soil samples by soil textural classes. The ☆ marks average soil texture.

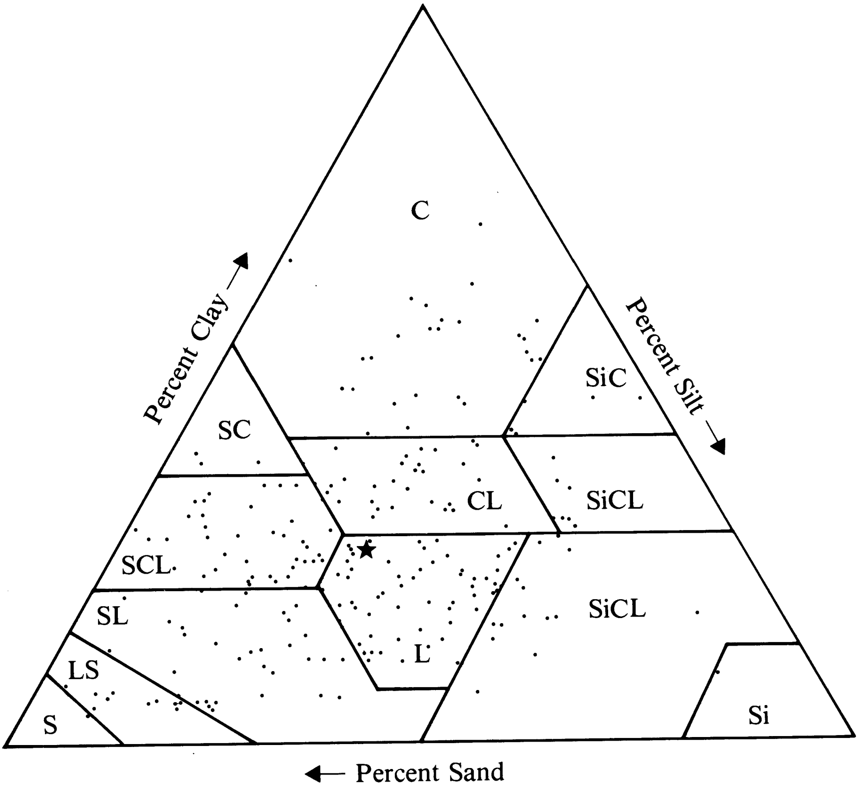


Figure 6.—Distribution of 223 subsoil samples by soil textural classes. The ☆ marks average soil texture.

Table 13.—Disturbance categories of attacked plots—Kisatchie National Forest

Disturbance	Attacked (1,679)
	Percent
1. No known disturbance	41.1
2. Logging activity within previous yr	5.6
3. Logging activity more than 1 yr ago	0.4
4. Ice and/or hail damage, severe—over one-half of stems affected	0.8
5. Ice and/or hail damage, light—less than one-half of stems affected	0.7
6. Fire within previous yr	0.6
7. Fire more than 1 yr ago	0.7
8. Lightning strike evident	34.5
9. Chem. brush control within yr	0.4
10. Chem. brush control more than 1 yr ago	0.0
11. Wind damage	12.1
12. Other	3.1
Total	100.0

Among all detected SPB infestations, 59 percent were associated with some kind of disturbance (table 13). Lightning was by far the most frequent disturbance encountered (35 percent). It was a significant factor associated with infestations over the entire study period, especially from midsummer through fall or early winter. At 12 percent, wind damage was the second most frequent disturbance. Most of the wind damage was associated with the Kisatchie Ranger District following a tornado in the spring of 1976.

Table 14.—Basal area class of attacked plots in natural, undisturbed stands—Kisatchie National Forest

Basal area class	**Attacked (223)**
ft^2/acre	Percent
< 50	2.2
50–70	4.9
80–100	13.0
110–130	27.4
140–160	26.0
170–190	13.4
200–220	7.2
230–250	3.1
≧ 260	2.7
	100.0
Average BA in ft^2/acre	141.5
Average percent pine	77.3

Table 15.—Size and frequency distribution of infestations in natural, undisturbed stands—Kisatchie National Forest (n = 223)

Acres (nearest 0.25 acre)		**Percent of total**
Lower limit	Upper limit	
0.0	0.25	74.1
0.5	1.0	17.9
1.25	2.0	5.8
2.25	10.0	2.2
10.25	20.0	0.0
20.25	50.0	0.0
50.25	+	0.0
		100.0

More than half the infestations in natural, undisturbed stands had a total BA over 130 ft^2/acre; 80 percent had 110 ft^2 or more (table 14). Stands with such stocking and the average characteristics reported in table 11 probably could support sizable infestations. However, most were quite small, less than 1/4 acre (table 15). Of the infestations, 80 percent were active when plots were established. But moderately low populations of SPB and a generally rapid salvage control program throughout the 25-month study period likely contributed to the predominance of small infestations.

Cluster (10-point) Prism Plots.—We found little variation among Ranger Districts for tree and stand characteristics determined from the cluster plots in which acceptable plot trees were 5.0 inches d.b.h. and larger, and within the limiting distance of a 37.5 BA factor prism (table 16). Averages for characteristics of prism-selected trees (d.b.h., height, and crown ratio) are for the tree of average BA. Based on these data the average SPB infestation in the Kisatchie National Forest was in pure pine type (78 percent pine) and immature sawtimber stand condition class (44 years old and 11.0 inches d.b.h.). Site index for loblolly pine was 93; BA/acre of the stand for this average SPB infestation exceeded the maximum leave BA suggested in the *Technical Guide for Timber Marking*[3] by 40 ft^2, if the hardwood basal area is included.

Average BA for the cluster plots was about 22 ft^2/acre lower than for the single-point plots (table 11). Most of the difference was due to higher BA associated with single-point plot data—that is, in the immediate vicinity of the infestation origin. These data indicate a strong tendency for infestations to start in the more dense pockets of otherwise well-stocked pine stands.

In Louisiana, loblolly pine was the primary forest type attacked: 249 plots had 70 percent or more of their BA in loblolly pine. The principal apparent differences among the pine species were that the average infested stand of shortleaf was about 10 years older, had a lower total BA (106 ft^2/acre *v.* 125 ft^2), and a larger diameter (dominant stand) than loblolly (13.2 in *v.* 12.6 in). Infested longleaf and slash pine stands had considerably less hardwood than either loblolly or shortleaf, and the few infested slash pine stands were mostly young, well-stocked plantations.

[3]Section 2442.8, Kisatchie National Forest Supplement No. 46, November 1972, to the *Forest Service Manual.*

Table 16.—Tree and stand characteristics of 10-point cluster plots (37.5 BA factor prism) in 318 southern pine beetle infestations—Kisatchie National Forest

Ranger District	No. of plots[1]	Age (yrs)	Si[2]	BA (ft^2/acre) Pine	Hdwd.	Total
Catahoula	71	44	93	95	22	117
Evangeline	68	41	95	104	26	130
Kisatchie	62	43	92	96	28	124
Winn	61	49	90	81	28	109
Vernon	35	45	96	95	25	120
Caney	21	42	101	96	30	126
Total	318	44	93	94	26	120

[1]Six of the total (324) plots were deleted because of missing data.

[2]Height at age 50 for loblolly pine only.

Table 17.—Volume per acre of SPB-infested stands (loblolly or shortleaf pine > 70 percent of the pine component)—Kisatchie National Forest

Ranger District	No. of plots	Average volume per acre[1] ft^3	Cords	fbm (Scribner)
Catahoula	68	2580	33.8	12,400
Evangeline	63	2800	36.7	13,600
Kisatchie	55	2680	35.2	13,300
Winn	59	2230	29.1	10,900
Vernon	23	3080	40.3	15,800
Caney	20	2560	33.7	12,700
Kisatchie NF	288	2610	34.2	12,800

[1]Arithmetic averages of volumes computed for individual plots (trees > 5.0 in d.b.h.).

All pines				Dominant pine stand			
d.b.h. (in)	Height (ft)	Trees/ acre	Crown ratio	d.b.h. (in)	Height (ft)	Trees/ acre	Crown ratio
11.1	69	141	0.32	12.4	74	100	0.34
11.0	66	157	0.34	12.0	70	118	0.37
10.9	67	148	0.32	12.2	72	100	0.35
11.0	65	123	0.32	12.3	71	88	0.35
11.2	69	138	0.32	12.1	71	108	0.33
10.9	67	148	0.30	11.8	72	113	0.32
11.0	67	143	0.32	12.2	72	103	0.35

Based on the latest forest survey report for Louisiana (Murphy 1975), poletimber and sawtimber stands in the Kisatchie National Forest averaged about 1,449 ft^3/acre and 7,100 fbm/acre (Int. 1/4-inch rule). In applying Myers' program YLDTBL to 288 plots that consisted of 70 percent or more of loblolly or shortleaf pine, we found that SPB-infested stands had about 1.6 times these expected volumes (table 17). These volume figures are further evidence of the character of SPB-infested stands in West Gulf Coastal Plain forests. Although some variation existed among Ranger Districts, infested stands ranged from 2,200 to 3,100 ft^3, 34 to 40 cords, and 10.9 to 15.8 M fbm/acre.

In summary, examination and analysis of the cluster plot data indicates that SPB infestations occurred in well-stocked to over-stocked, natural stands of sawtimber-sized loblolly pine on productive sites. They tended to originate in the more heavily stocked portions of these stands. Hardwoods 5.0 inches d.b.h. or larger comprised about 22 percent of the stocking; and if this component were ignored, stocking would appear moderate when in reality it could be excessive.

Table 18.—Occurrence of SPB infestations by stand condition classes, all forest types—Kisatchie National Forest

Stand condition class	Area[1]		Infestations[2]	
	Percent			
Sawtimber				
Damaged, sparse, & low quality	3.3		3.5	
Mature	14.3		16.9	
Immature	39.2		51.4	
Subtotal		56.8		71.8
Poletimber				
Damaged, sparse, & low quality	0.7		0.5	
Mature	<0.1		0.0	
Immature	17.0		17.9	
Subtotal		17.7		18.4
Seedling & sapling[3]	17.9		6.8	
Subtotal		17.9		6.8
In regeneration	7.1		1.7	
Shortleaf-littleleaf disease	0.0		0.0	
Nonstocked	0.2		0.1	
Unclassified	0.3		1.2	
Subtotal		7.6		3.0
Total		100.0		100.0

[1]Total area 522,704 acres.

[2]Total infestations 1679.

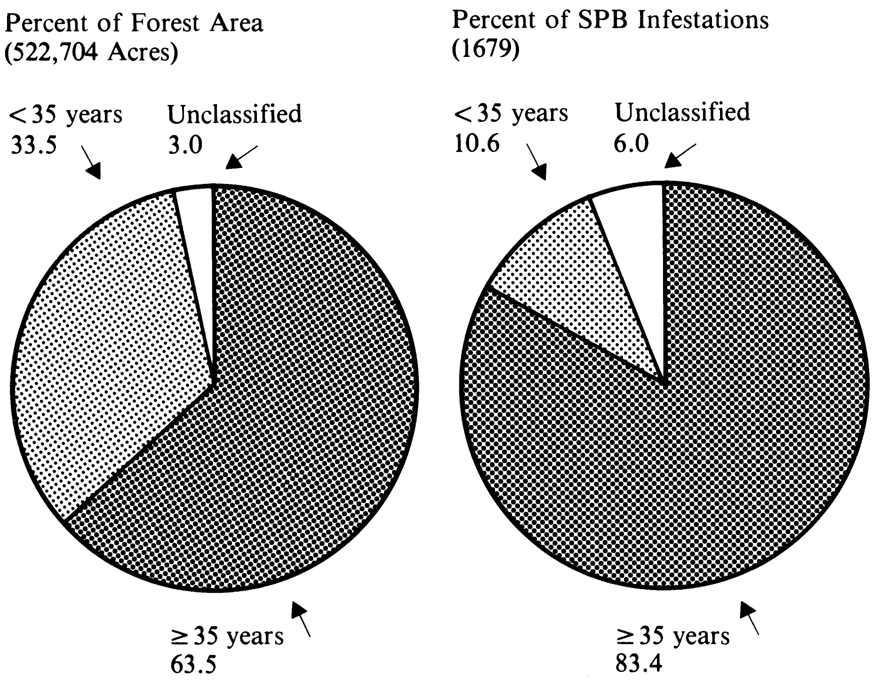
[3]Adequately and inadequately stocked.

Forest Resource Characteristics.— The Kisatchie National Forest is about 84 percent pine forest. SPB infestations occurred primarily in pine type—85 percent *v.* 10.5 percent in hardwood-pine, 3.3 percent in hardwood, and 1.2 percent in unclassified. Within the pine types, loblolly pine had a disproportionately high frequency of infestations (66 percent) and shortleaf a proportionate frequency (7 percent) in relation to area in those types. Longleaf and slash types both had lower infestation frequencies than might be expected based on area in those types. Virtually all of the infestations that occurred in hardwood-pine type were on lower slopes and stream bottoms where loblolly was the predominant pine species. Loblolly and shortleaf pine are both considered preferred hosts of SPB, but in this area loblolly may be the most preferred as well as the most abundant type available to bark beetle populations.

Fifteen stand condition classes are recognized in the forest resource data. For our purposes, the 15 classes were condensed to 11 by combining the damaged, sparse, and low-quality classes for the sawtimber and the poletimber size. Infestations were disproportionately distributed among stand condition classes (χ^2 significant at .01 probability): a higher percentage of infestations occurred in sawtimber condition classes than expected based on the area they occupied (table 18). Immature and mature sawtimber stand condition classes had 68 percent of the infestations but occupied only 54 percent of the area. Immature sawtimber alone was associated with more than half the infestations.

Within pine management types (areas committed to producing a stand composed of 70 percent of a selected pine species), infestations occurred more frequently on the better sites as indicated by their distribution across CISC data site index classes: about 90 percent of the infestations occurred in site index classes 80 or higher. These observations agree with the results for site characteristics of the sample plots, as well as the high average stand volumes reported in table 17.

About 64 percent of the forest was in stand age classes 35 years and over; 83 percent of the infestations occurred in these age classes (fig. 7). Distribution of infestations across 10-year age classes for pine management types showed that trees in age class 35 were most often infested. Further, for loblolly pine management type the area frequency distribution of age classes differed significantly from the SPB infestation distribution. Disproportionately more infestations occurred in age classes 35 years and older (χ^2 significant at .01 probability), with a dramatic increase in infestations at age class 35 (fig. 8).



In summary, forest type, stand condition class, site index, and age of stands reported in CISC data showed some consistent associations with SPB infestations. Loblolly pine type, immature and mature sawtimber, on sites with an index of 80 or higher, and in age classes 35 or older comprised the great majority of infestations.

Acknowledgments
Sincere appreciation is extended to field crew leaders Steven P. Weaver and John F. Kramer. Cooperation of the Kisatchie National Forest personnel, both in the Supervisor's Office and on the Ranger Districts, is also greatly appreciated. The Office of the Regional Forester, Inventory and Plans, was most helpful in providing essential information on the CISC system and the data. Southeastern Area, State and Private Forestry, Forest Insect and Disease Management gave valuable assistance in locating infestations.

Figure 7.—Distribution of forest area and SPB infestations by stand age groups.

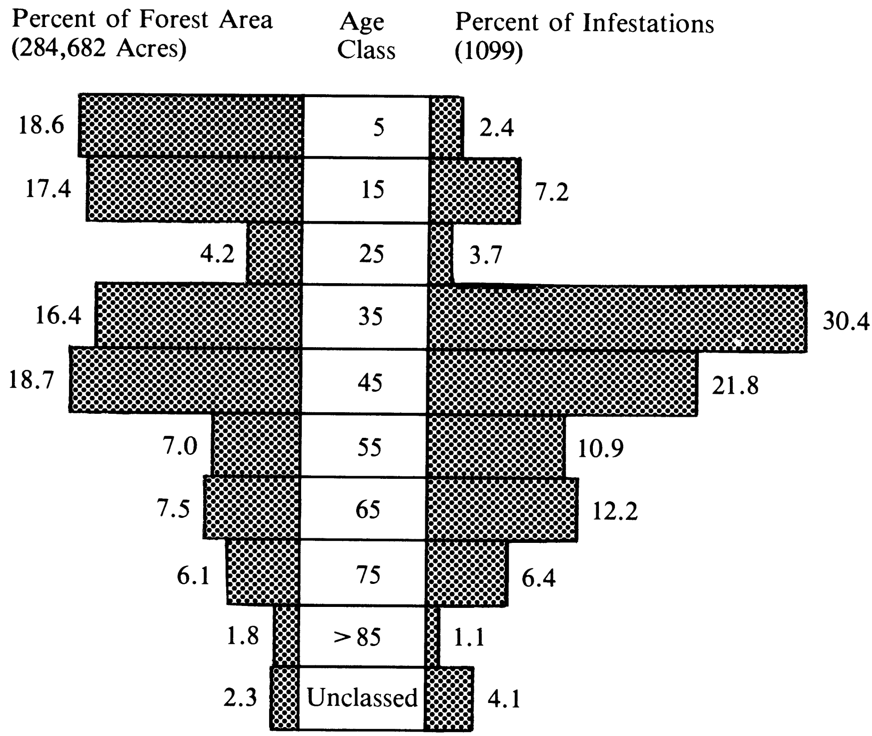


Figure 8.—Distribution of SPB infestations by 10-year age classes within pine management type.

Southern Mississippi, Louisiana, and Eastern Texas

Ronald J. Kushmaul and
Michael D. Cain

Study Area

Six timber corporations participated in this research effort. Their combined forest and landholdings included parts of 10 east Texas counties, 27 Louisiana parishes, and 19 southern Mississippi counties (fig. 9). Approximately 2,235,000 acres comprised the study area.

During the research period (May 1975 to August 1977), corporate foresters, the Texas Forest Service, and the Louisiana Office of Forestry provided reports of SPB infestations. At the end of our research, the total number of reports received from each company's holdings by county or parish was multiplied by the average size of sampled spots on those holdings; that figure was then divided by acreage to obtain an intensity estimate for each company/county unit. Using these estimates, we grouped units with similar intensity levels and established the geographical distribution for five intensity levels (fig. 10). Since different intensity levels occurred within several Louisiana parishes (because of different company ownerships), those parishes are delineated more than once in figure 10.

Figure 9.—Counties or parishes included in the Louisiana, Mississippi, and east Texas study area (2,235,000 acres).

Figure 10A.—Geographical distribution of reported beetle activity—Intensity level 1 (0 to 0.149 infested acres/1,000 acres). Total acres 1,139,000. Longleaf, slash, and spruce pine, considered to be less susceptible to SPB attack, predominate in southeast Louisiana. Large acreages of longleaf and slash pine also occur in south central Louisiana and southern Mississippi.

Figure 10B.—Beetle activity at intensity level 2 (0.150 to 0.349 infested acres/1,000 acres). Total acres 459,000. Stand composition is, generally, mixed loblolly-shortleaf with some pure loblolly stands and a few pure shortleaf stands.

Figure 10C.—Beetle activity at intensity level 3 (0.350 to 0.899 infested acres/1,000 acres). Total acres 273,000. Stands are mostly pure loblolly or loblolly-shortleaf, or infrequently pure shortleaf.

Figure 10D.—Beetle activity at intensity level 4 (0.900 to 3.999 infested acres/1,000 acres). Total acres 321,000. More pure loblolly stands occur here than at the lower infestation levels, but numerous mixed loblolly-shortleaf stands also exist. Also, there are a few pure slash stands.

Figure 10E.—Beetle activity at intensity level 5 (4.000 to 39.000 infested acres/1,000 acres). Total acres 43,000. Many overmature stands of pure loblolly. Some stands are loblolly mixed with shortleaf, while a few are loblolly mixed with slash or longleaf.

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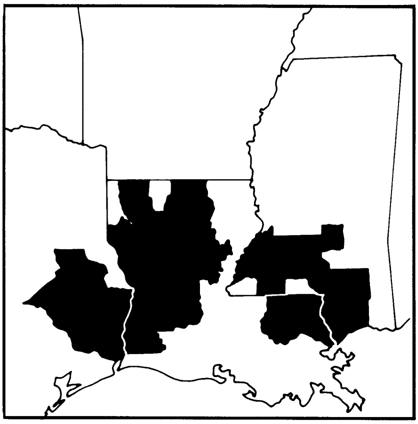
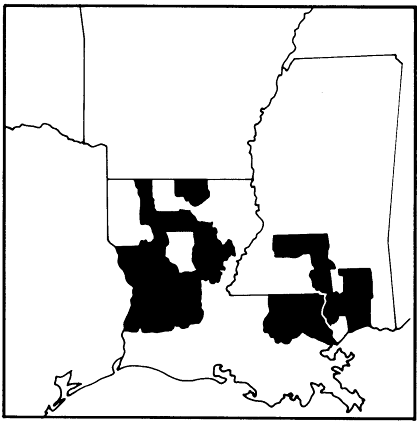


10A



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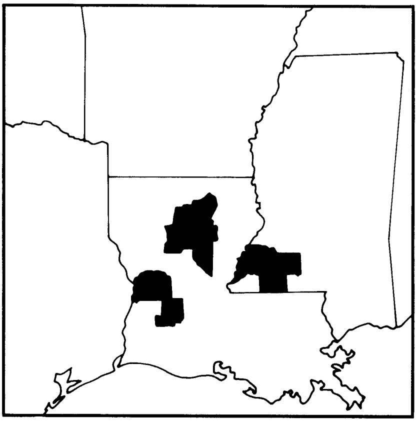

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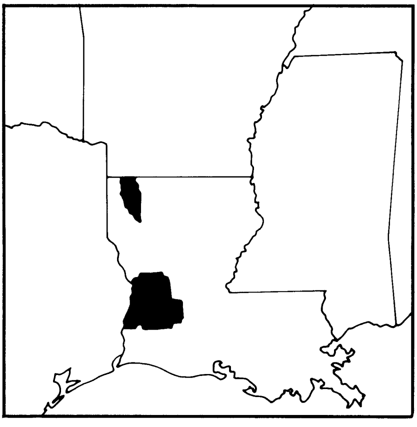

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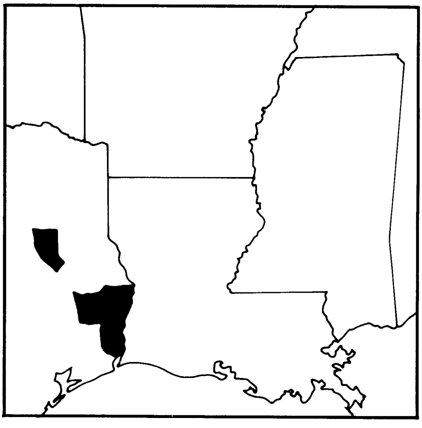

Additional Procedures
In this study we obtained baseline data by measuring Continuous Forest Inventory (CFI) plots maintained by the six cooperating companies. Plots located in stands of pure longleaf or slash pine, and stands having only pines < 5 inches d.b.h. were not sampled because they are normally less susceptible to beetle activity. We measured a 20-percent random subsample of approximately 1,800 CFI plots to establish a baseline data set representing the loblolly and shortleaf pine forests and mixed pine-hardwood forests in the study area.

Results and Discussion
Analysis of variance indicated that the means for the following variables differ significantly among the infested and baseline data sets at least at the 0.05 level:

Slope, surface soil pH, subsoil pH, pine BA, total BA, stand understory, stand density, site index, average bark thickness—fissure, average bark thickness—ridge, average radial growth 0 to 5 years, and average radial growth 6 to 10 years.

Based on these variables, the characteristics of infested plots were:

Slope—Flatter slopes had more infestations.
Soil pH—pH of surface and subsoils was lower in infested plots.
Basal area—Infested stands had higher pine BA as well as higher total BA.
Understory—The percent area occupied by the understory was higher in infested plots.
Stand density—Infested plots occurred in stands of higher density.
Site index—Higher site indices were found for infested plots.
Bark thickness—Trees in infested plots had thicker bark.
Radial growth rate—Growth of infested stands had slowed during the last 10 years.

Table 19.—Landform classification of attacked and baseline plots in natural, undisturbed stands—Mississippi, Louisiana, Texas Coastal Plain

Landform	Attacked (122)	Baseline (139)
	Percent	
1. Flood plain	2.5	0.0
2. Stream terrace	9.0	14.4
3. Bay	14.8	8.6
4. Upland flat	27.0	21.6
5. Lower slope	3.3	1.4
6. Side slope	22.1	37.4
7. Steep side slope	9.8	8.6
8. Ridge	7.4	6.5
9. Other	4.1	1.5
	100.0	100.0

Landform.—Infestations apparently occur more often in association with the less well-drained landforms (table 19). The relationship between individual landforms and beetle incidence was not significant (χ^2 tests). When the cumulative frequencies of the various landforms are compared, however, the five flatter landforms have a disproportionate share of beetle spots. The lower average slope for infested plots compared to baseline (table 20) substantiates the observation that stands growing on flatter, less well-drained landforms were attacked more often. Lorio et al. (1972) related soil drainage conditions to susceptibility through the effect on root structure.

Table 20.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—Mississippi, Louisiana, Texas Coastal Plain

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago

*Mean and standard deviation for those plots with nonzero slope and aspect.

Units	Attacked plots (122)		Baseline plots (139)	
	Mean	SD	Mean	SD
%	5.9	4.8	7.5	7.0
degree	186.0	112.2	179.3	113.1
%	49.3	20.1	49.3	21.4
%	38.6	16.6	38.3	18.0
%	12.1	7.7	12.4	8.0
$\log \frac{1}{[H^+]}$	4.6	0.4	4.8	0.4
cm	32.6	19.8	31.9	19.4
%	42.4	20.2	41.2	21.1
%	34.6	15.4	34.9	16.8
%	23.0	12.7	23.9	13.1
$\log \frac{1}{[H^+]}$	4.6	0.4	4.8	0.4
ft^2/acre	108	41.2	57	36.4
ft^2/acre	31	23.1	39	33.6
ft^2/acre	139	39.8	96.5	37.2
%	56	22.2	50	25.8
years	44	13.6	44	16.3
trees/acre	736	998.6	606	658.4
ft	94.3	11.3	90.0	12.2
number	188.9	346.8		
in	0.4	1.0	0.4	0.1
in	0.8	0.2	0.8	0.2
mm	15.0	4.9	18.7	7.9
mm	16.4	6.2	21.2	9.0

Table 21.—Size and frequency distribution of infestations—Mississippi, Louisiana, Texas Coastal Plain

Acres (nearest 0.25 ac)		Percent of total	
Lower limit	Upper limit	All plots (245)	Natural, undisturbed plots (122)
0.0	0.25	50.5	41.0
0.5	1.0	23.7	20.5
1.25	2.0	9.8	14.8
2.25	10.0	12.7	18.9
10.25	20.0	3.3	4.9
20.25	50.0	0.0	0.0
50.25	+	0.0	0.0
		100.0	100.0
Avg. spot size (acres)		1.7	2.4

Disturbances.—The average size of infestations occurring in natural, undisturbed stands is greater than for infestations in general (table 21). Although stand origin (plantation *v.* natural) may also be a factor, these averages tend to substantiate earlier reports that disturbance-related infestations are usually small (Ku et al. 1976).

Comparisons of individual disturbances show some interesting differences between infested and baseline plots (table 22). First, recent logging activity occurs more frequently on infested spots than on baseline plots. Past logging disturbance, however, is much more frequently associated with baseline plots. This indicates that recent logging activity, perhaps because of the initial damage to trees and soil, is an ''inducing'' disturbance. Older logging seems to inhibit activity, though—perhaps because of the thinning effect. Second, recent fire slightly reduces beetle attacks. This could be because of improved soil moisture balance through the reduction in understory or other causes. Third, lightning is clearly associated with beetle activity, occurring much more often in infested stands than in stands in general. This finding agrees with earlier studies regarding the inducing effect of lightning on SPB attacks (Hodges and Pickard 1971, Ku et al. 1976). Finally, chemical brush control apparently has a long-term beneficial effect similar to that observed for logging.

*Table 22.—Disturbance categories of attacked and baseline plots—Mississippi, Louisiana, Texas Coastal Plain**

Disturbance	Attacked (245)	Baseline (356)
	Percent	
1. No known disturbance	33.6	31.3
2. Logging activity within previous yr	12.3	8.8
3. Logging activity more than 1 yr ago	8.6	21.8
4. Ice and/or hail damage, severe—over one-half of stems affected	0.4	0.0
5. Ice and/or hail damage, light—less than one one-half of stems affected	2.0	9.9
6. Fire within previous yr	1.6	3.9
7. Fire more than 1 yr ago	16.0	14.8
8. Lightning strike evident	19.3	2.4
9. Chem. brush control within previous yr	0.8	0.0
10. Chem. brush control more than 1 yr ago	1.2	4.4
11. Wind damage	4.2	2.7
12. Other	0.0	0.0
	100.0	100.0

*A plot may have more than one disturbance.

Basal area and site index.—Classed data for total BA (table 23) and site index (table 24) show that infested plot frequencies are skewed toward the higher values of both variables. Total BA and site index are significantly and directly correlated in both the infested and baseline data (table 25).

Since this correlation, especially for the pine component, is more pronounced in the infested data, beetle activity appears to be favored in stands where BA approaches the maximum potential of site quality. Therefore, stands with high BA may be more susceptible to attack during environmental stress conditions (e.g., drought) that temporarily reduce site quality.

Table 23.—Basal area class of attacked and baseline plots in natural, undisturbed stands—Mississippi, Louisiana, Texas Coastal Plain

Basal area class	**Attacked (122)**	**Baseline (139)**
ft^2/acre	Percent	
< 50	0.0	10.1
50–70	3.3	19.4
80–100	15.6	34.6
110–130	32.8	20.1
140–160	25.4	11.5
170–190	12.3	4.3
200–220	6.6	0.0
230–250	4.0	0.0
≧ 260	0.0	0.0
	100.0	100.0
Average BA in ft^2/acre	139.0	96.5
Average percent pine	77.6	59.2

The significantly lower average radial growth rate for dominant and codominant pines on infested plots (table 20) indicates that a decline in vigor, possibly caused by excessive competition, often precedes beetle attack. These data suggest the dynamic relationship between site and stand factors in predisposing beetle activity.

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Table 24.—Site index class of attacked and baseline plots in natural, undisturbed stands—Mississippi, Louisiana, Texas Coastal Plain

Site index class	**Attacked (122)**	**Baseline (139)**
Base age 50 yrs	Percent	
0–50	3.3	7.2
50–59	0.0	0.0
60–69	1.6	5.8
70–79	7.4	11.5
80–89	23.0	27.3
90–99	30.2	28.8
100–109	27.9	15.8
110–119	6.6	2.2
120–129	0	1.4
	100.0	100.0
Average site index	94.3	90.0

Table 25.—Correlation coefficient analysis of site index-basal area relationship—Mississippi, Louisiana, Texas Coastal Plain

Variable pair	**Level of significance**[1]	
	Infested (122)	Baseline (139)
Pine BA with site index	0.003 S	0.440 NS
Hardwood BA with site index	.004 S	.008 S
Total BA with site index	.001 S	.010 S

[1]The letter S denotes correlations significant at least at the 0.05 level.

Association of Annosus Root Rot with Southern Pine Beetle Attacks

John M. Skelly, Samuel A. Alexander, and Roger S. Webb

Study Area

The incidence of the root rot *Heterobasidion annosum* (Fr.) Bref. (*Fomes annosus*) in loblolly pine stands and its severity were measured in Coastal Plain forests in Virginia, Georgia, and Texas, to better understand the role of annosus root rot as an agent in predisposing loblolly pine and other pine species to attack by SPB.

Additional Procedures

We took the site, stand, and tree measurements described in other sections, and also excavated the entire root systems of all pine trees in the BA plots using a bulldozer. Unattacked plot data are of the control plot type. These plots were located about two chains from the attacked plot center. Each tree's root system was rated as to its overall size and appearance and a visual examination was made to determine if *H. annosum* occurred in the root system. If a tree had more than 1 percent of its root system affected by *H. annosum,* detailed measurements were taken. Our field team measured the primary and secondary roots of all such trees, checking the number and length of affected and healthy roots and the base diameter of each root. Observers divided the measured root length into three symptomatic categories: (1) healthy, (2) resin-soaked, and (3) stringy. Categories 2 and 3 were considered symptomatic expressions of the presence of *H. annosum*. At periodic intervals, and whenever plots were being established in new geographical areas, roots with the three symptom categories were taken to the laboratory and the presence or absence of *H. annosum* was verified by selective isolation techniques.

Increment growth for the past 0–5 and 6–10 years was taken for each tree. Field teams also measured annual increment growth for all "in" pines. They removed a disk from each tree at breast height and made measurements at four points on the disk, the fastest and slowest growth rates, and the two adjacent sides.

Only those SPB sites infested less than 8 weeks were selected for plot establishment. Plots were established only in areas judged to be moderate- to high-hazard annosus sites. In moderate-hazard sites the surface soil contains 55 percent to 70 percent sand; high-hazard sites contain greater than 70 percent sand in the surface soil (Morris and Frazier 1966).

A total of 30 plots (15 attacked, 15 control) were established: 11 in Virginia (1100-series plots), 3 in Texas (1900-series plots), and 1 in Georgia (plot 1401).

Results and Discussion

The primary objectives of this study were to determine if an association between the occurrence of *H. annosum* and SPB infestations exists and if *H. annosum* predisposes pines to SPB attack by reducing radial growth. Plot locations were in Coastal Plain loblolly pine plantations and natural stands. A total of 335 trees in 30 plots were measured and their root systems excavated and rated, with 76 trees measured for *H. annosum* colonization.

In the attacked and control plots, field crews measured 52 and 29 trees, respectively, for *H. annosum* (more than 1 percent colonization). The average incidence of colonization for attacked and control plots was 37 and 45 percent, respectively; and for those trees with more than 1 percent of their root systems colonized, the incidence was 21 and 13 percent, respectively. For the control plots the incidence of colonization for all trees and those with more than 1 percent colonization was 74 and 31 percent, respectively. Observers found conks in only 7 of the 51 plots.

Table 26 records the incidence and severity of *H. annosum* on moderate- to high-hazard annosus root rot sites in SPB-attacked and control plots. The overall incidence (at least one affected root per tree) of *H. annosum* in 92 trees on 9 attacked plots was 65 percent; in 98 trees on 9 control plots, the disease incidence was 73 percent. And 41 percent of the attacked plot trees had more than 1 percent of their root systems affected by *H. annosum*. In the control plots, 26 percent were so affected. Table 27 summarizes incidence and severity levels in natural stands. The incidence in 66 trees in 6 attacked plots was 24 percent, and in 79 trees in 6 control plots was 13 percent. None of the unattacked natural stands had trees with more than 1 percent of their roots colonized, and only 18 percent of the trees on SPB-attacked plots were so colonized. A comparison of plantations and natural stands indicates the same trends in colonization levels but with the higher amounts found in plantations.

Table 26.—Heterobasidion annosum *colonization levels in attacked and control plots established on high-hazard* H. annosum *sites—Coastal Plain plantations*

Plot	Total no. trees	% Trees without annosum	% Trees with infected root	% Trees with >1% root system infected	No. conks
Attacked					
1101	9	0	100	100	1
1102	13	15	85	31	0
1103	14	43	57	29	0
1104	11	82	18	18	0
1105	9	56	44	0	0
1106	8	37	63	50	0
1401	10	0	100	40	1
1902	8	12	88	88	0
1903	10	60	40	40	1
Total	92				3
Average		35	65	41	
Control					
2101	8	12	88	75	0
2102	14	21	79	0	0
2103	13	46	54	15	0
2104	15	0	100	20	0
2105	5	0	100	80	0
2106	4	25	75	50	0
2401	15	0	100	13	0
2902	10	50	50	30	0
2903	14	71	29	29	0
Total	98				0
Average		27	73	26	

Table 27.—Heterobasidion annosum *colonization levels in attacked and control plots established on high-hazard* H. annosum *sites—natural, undisturbed Coastal Plain stands*

Plot	**Total no. trees**	**% Trees without annosum**	**% Trees with infected root**	**% Trees with >1% root system infected**	**No. conks**
Attacked					
1107	4	100	0	0	0
1108	14	86	14	14	0
1109	13	77	23	15	0
1110	13				
1117	12	58	42	33	0
1901	10	48	60	40	0
Total	66				0
Average		76	24	18	
Control					
2107	8	100	0	0	0
2108	18	89	11	0	0
2109	12	75	25	0	0
2110	8	100	0	0	0
2117	13	77	23	0	0
2901	20	90	10	0	0
Total	79				0
Average		87	13	0	

Table 28.—Average percent Heterobasidion annosum *colonization of all trees in attacked and control plots—Coastal Plain plantations*

Plot	No. trees	% Colonization[1]
Attacked		
1101	9	54.9
1102	13	16.6
1103	14	14.8
1104	11	4.7
1105	9	0.2
1106	8	33.9
1401	10	17.2
1902	8	51.0
1903	10	13.9
Total	92	
Average		23.1
Control		
2101	8	23.1
2102	14	0.4
2103	13	5.1
2104	15	7.7
2105	5	14.9
2106	4	26.6
2401	15	3.4
2902	10	12.3
2903	14	2.1
Total	98	
Average		10.9

[1]T-Test significance P = 0.05.

Table 28 summarizes the average percent of *H. annosum* colonization of all "in" pines for the attacked and control plots. We determined these percentages by measuring the primary and secondary roots of all trees with more than 1 percent of their root systems colonized, by assigning a value of 0.5 percent colonization for those trees colonized but having less than 1 percent colonization, and by assigning 0.0 percent colonization for those trees that were not colonized. The aver-

Table 29.—Average percent Heterobasidion annosum *colonization of all trees in attacked and control plots—natural, undisturbed Coastal Plain stands*

Plot	No. trees	% Colonization[1]
Attacked		
1107	4	0.0
1108	14	3.6
1109	13	13.1
1110	13	
1117	12	29.2
1901	10	14.2
Total	66	
Average		12.0
Control		
2107	8	0.0
2108	18	0.1
2109	12	0.1
2110	8	0.0
2117	13	0.1
2901	20	0.1
Total	79	
Average		0.1

[1]T-Test significance P = 0.028.

age *H. annosum* colonization for the attacked and control plots was 23.1 percent and 10.9 percent, respectively, significant at P = 0.05. Table 29 summarizes the average percentage *H. annosum* colonization for the natural stands. The average percentage colonization for attacked and control plots was 12.0 percent and 0.1 percent, respectively. This is the same trend as found in the plantations but at a lower level. Variation in the natural stands exceeded that in the plantations.

Table 30.—Number of roots in measured loblolly pine in attacked and control plots and the number and percent colonized with Heterobasidion annosum—*Coastal Plain plantations*

Plot	Total no. roots	Total no. roots colonized	Percent colonized[1]
Attacked			
1101	645	246	38
1102	443	255	58
1103	326	127	39
1104	254	64	25
1105	0	0	0
1106	312	166	53
1401	75	34	45
1902	667	334	50
1903	198	49	25
Total	2920	1275	
Average			44
Control			
2101	722	227	31
2102	0	0	0
2103	93	29	31
2104	248	91	37
2105	314	60	19
2106	210	100	48
2401	161	36	22
2902	330	46	14
2903	265	18	7
Total	2343	607	
Average			26

[1]T-Test significance P = 0.03.

Table 30 summarizes the root colonization data for all measured (>1 percent *H. annosum*) root systems. The average total number of roots per tree measured and colonized with *H. annosum* per tree for the attacked plots was 32 and 14, and for the control plots 24 and 6, respectively. For attacked and control plots, the average percent colonization was 44 (0–58 percent) and 26 (0–48 percent), respectively. There was a significant difference (P = 0.03) between colonization levels with the higher *H. annosum* colonization in the SPB plots. In natural loblolly stands located in the Coastal Plain, the percentage *H. annosum* colonization was 12.5 and 0.5 for the SPB-attacked and control plots.

Table 31 records a summary of the total root length, both healthy and colonized with *H. annosum,* for SPB-infested and noninfested trees in the attacked plots. The percentage of *H. annosum* in the SPB-infested and noninfested trees was 80 and 18, respectively, significantly different at P = 0.001. The percentage colonization in the secondary roots was significantly different (P = 0.01) with 44 and 13, respectively, for infested and noninfested trees.

Table 32 summarizes the total number of roots colonized with *H. annosum* and the number healthy for SPB-infested and noninfested trees in attacked plots. The percentage colonization was 86 and 32, respectively, for SPB-infested and noninfested trees. This difference was significant (P = 0.001).

Table 31.—Total root length infected by Heterobasidion annosum *in measured loblolly pine in attacked and nonattacked plots—Coastal Plain plantations*

Plot	Tree no.	Total length	Total length colonized	% Colonization[1]
Attacked				
1401	7	635	208	33
	8	251	112	45
	9	221	44	20
	10	182	27	15
1101	3	568	548	96
	4	294	211	72
	5	294	244	83
	6	201	46	23
1102	5	2311	2161	94
1103	8	244	201	82
	14	420	239	57
1106	4	629	629	100
	5	449	449	100
1902	5	3996	3224	81
	6	285	285	100
1903	4	631	627	99
Total		11611	9255	
Average				80

[1]T-Test significance P = 0.001.

Plot	Tree no.	Total length	Total no. colonized	% Colonization[1]
Nonattacked				
1101	1	11240	247	2
	2	1615	322	20
	7	2486	494	20
	8	524	191	36
	9	2084	661	32
1102	3	786	127	16
	4	2314	424	18
	7	1612	375	23
1103	6	1182	251	21
	7	3473	556	16
1104	4	1959	194	10
	6	3106	111	4
1106	7	1062	215	20
	8	1213	184	15
1902	1	2653	168	6
	3	3140	499	16
	4	1253	160	13
	7	513	513	100
	8	2067	797	39
1903	5	1343	46	3
	6	1127	62	6
	8	654	36	6
Total		47406	6633	
Average				18

Table 32.—Total number of roots infected by Heterobasidion annosum *in measured loblolly pine in attacked and nonattacked plots—Coastal Plain plantations*

Plot	Tree no.	Total no.	Total no. colonized	% Colonization[1]
Attacked				
1101	3	36	36	100
	4	19	17	89
	5	15	14	93
	6	13	3	23
1102	5	150	143	95
1103	8	17	13	76
	14	23	13	57
1106	4	57	57	100
	5	33	33	100
1401	7	25	15	60
	8	24	11	46
	9	14	3	21
	10	12	5	42
1902	5	140	128	91
	6	23	22	96
1903	4	28	27	96
Total		629	540	
Average				86

[1]T-Test significance P = 0.001.

Plot	Tree no.	Total no.	Total no. colonized	% Colonization[1]
Nonattacked				
1101	1	258	54	21
	2	69	20	29
	7	93	36	39
	8	27	15	56
	9	115	51	44
1102	3	75	37	49
	4	124	47	38
	7	94	28	30
1103	6	67	25	37
	7	219	76	35
1104	4	116	37	32
	6	138	27	20
1106	7	86	35	41
	8	136	41	30
1902	1	128	16	13
	3	140	49	35
	4	73	18	25
	7	43	43	100
	8	120	58	48
1903	5	75	6	11
	6	58	9	16
	8	37	7	19
Total		2291	735	
Average				32

Table 33.—Average percent Heterobasidion annosum *infection for SPB-infested and noninfested trees in attacked plots—Coastal Plain plantations*

Plot	**No. trees**	**Average percent colonization**[1]	
		Infested trees	Noninfested trees
1101	9	76	38
1102	13	32	12
1103	14	44	7
1104	11	0	5
1105	9	0	0
1106	8	100	12
1401	10	42	1
1902	8	94	37
1903	10	96	5
Average	10.2	54	11

[1]T-Test significance P = 0.0001.

The average percentages of *H. annosum* colonization in SPB-infested and noninfested trees within the attacked plots were 54 percent and 11 percent, respectively (table 33). The difference between these mean percentages was significant (P = 0.001). The data indicate that within the immediate area attacked by SPB, *H. annosum* is associated significantly with those trees infested by the beetle. The conservative measurement of the level of *H. annosum*-colonized roots is indicated by the increased length of roots measured in trees with reduced levels of colonization. This would indicate more *H. annosum* in the root systems than was measured.

Annual radial growth, as measured on a dendrochronograph, was analyzed for each tree in the beetle-attacked control plots. The mean annual growth for the past 10 years was significantly different (P = 0.002) between the attacked and control plots. For 0–5 years and 6–10 years, SPB plots grew an average of 8 percent and 7 percent less, respectively, than the control plots. Mean colonizations for SPB and control plots were 23.1 percent and 10.9 percent, respectively (table 28).

Table 34.—Mean annual radial growth for each of the last 10 years for SPB-infested and noninfested trees located in SPB plots established on high-hazard (> 70% sand) H. annosum *sites—Coastal Plain plantations*

Years ago	SPB-infested (22)	Noninfested (70)	Difference[1]
	mm		Percent
1	1.21	1.87	-35
2	1.34	1.98	-32
3	1.38	1.70	-19
4	1.22	1.75	-30
5	1.04	1.31	-21
6	1.15	1.31	-12
7	1.30	1.63	-20
8	1.47	1.69	-13
9	1.63	1.93	-16
10	1.90	1.87	+2
Avg. 0–5 yrs ago	1.24	1.72	-28
Avg. 0–10 yrs ago	1.49	1.69	-12

[1]T-Test significance P = 0.001.

Table 34 summarizes mean annual radial growths over the last 10 years for SPB-infested and uninfested trees. These plots were located on high-hazard annosus sites (> 70 percent sand) in thinned loblolly pine plantations. The difference between the SPB-infested and non-infested was significant (P = 0.001). SPB-infested trees grew 28 percent and 12 percent less than the noninfested trees for 0–5 years and 6–10 years, respectively. These data establish the growth loss in SPB-attacked trees and the significantly higher levels of *H. annosum* present in the root systems of these trees. This association strongly suggests that *H. annosum* was stressing those trees attacked by SPB, as expressed through the reduced radial growth.

Means and standard deviations for selected soil, plot, and tree variables in loblolly pine plantations and natural stands are summarized in tables 35 and 36. Comparing the average radial growth for 0–5 and 6–10 years for the SPB-attacked against that for unattacked plots in plantations suggests that reduced radial growth is associated with SPB-attacked trees. The average ages for the plantations were 30 and 27 years, respectively, for SPB and control plots. Soil data establish the sites as high-hazard annosus root rot sites. Although plantations are generally uniform, the number of trees per acre was somewhat higher in the attacked plots.

Table 35.—Site and stand characteristics of attacked and baseline plots—Coastal Plain plantations

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago
H. annosum root colonization

*Mean and standard deviation for those plots with nonzero slope and aspect. Seventy-seven percent of the attacked stands had no slope.

Units	Attacked plots (9)		Baseline plots (19)	
	Mean	SD	Mean	SD
%	4.0	2.6	5.3	2.8
degree	105.0	10.2	170.0	90.8
%	81.7	5.4	83.5	4.9
%	11.2	4.9	9.8	4.2
%	7.1	2.9	6.6	2.6
$\log \frac{1}{[H^+]}$	4.8	0.5	4.7	0.8
cm	66.3	31.9	73.6	30.6
%	67.6	22.3	73.9	14.9
%	17.9	12.9	10.7	5.2
%	14.6	11.0	15.3	14.6
$\log \frac{1}{[H^+]}$	4.8	0.6	4.8	0.5
ft^2/acre	107	24.5	108	53.0
ft^2/acre	11	17.6	6	8.9
ft^2/acre	113	27.4	115	53.2
%	1	0.7	2	2.2
years	30	13.4	27	7.3
trees/acre	556	625.0	521	364.0
ft	74.9	12.0	84.9	11.9
number	2.4	1.2	0.0	0.0
in	0.5	0.2	0.4	0.1
in	0.8	0.2	0.9	0.1
mm	9.8	5.0	10.8	4.8
mm	10.0	4.1	12.7	6.4
%	23.1	31.9	10.1	18.9

Table 36.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed Coastal Plain stands

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago
H. annosum root colonization

*Mean and standard deviation for those plots with nonzero slope and aspect. Eighty-three percent of the attacked stands had no slope.

Units	Attacked plots (6)		Baseline plots (7)	
	Mean	SD	Mean	SD
%	1.7	4.1	2.1	5.7
degree	15.7	38.4	13.4	35.5
%	40.0	23.0	41.0	30.6
%	47.2	19.5	45.6	26.6
%	12.0	7.1	12.6	7.0
$\log \frac{1}{[H^+]}$	4.3	0.3	4.8	0.8
cm	61.5	23.3	56.7	23.2
%	33.8	24.4	36.7	26.1
%	39.2	14.4	43.6	24.5
%	25.8	11.5	24.9	17.8
$\log \frac{1}{[H^+]}$	4.6	0.5	4.8	0.5
ft^2/acre	117	22.5	170	69.8
ft^2/acre	32	24.8	13	17.0
ft^2/acre	148	30.6	183	70.7
%	67	15.1	65	15.5
years	45	20.9	36	16.0
trees/acre	616	370.2	1068	872.2
ft	76.6	10.8	72.6	32.7
number	4.3	3.0	0.0	0.0
in	0.8	0.4	0.8	0.5
in	0.6	0.3	0.8	0.5
mm	7.6	7.0	7.0	5.2
mm	9.8	11.3	9.7	8.9
%	12.5	27.9	0.5	1.9

The association of high *H. annosum* colonization levels with SPB infestation on high-hazard annosus root rot sites was clearly significant. This association between annosus root rot and occurrence of SPB infestations was greatest in thinned loblolly plantations. On low-hazard annosus root rot sites, however, this association was considerably weaker; and *H. annosum* appeared to play a much-reduced role regarding SPB attacks. Between SPB-infested and uninfested trees, the annual radial growth was significantly greater in uninfested trees, suggesting that the SPB-infested trees were less vigorous.

This study concludes that on deep, sandy soils (high-hazard annosus root rot sites) the incidence and/or severity of SPB infestations is associated with reduced growth rate (vigor) and this reduced vigor is due, in part at least, to the high disease levels of *H. annosum* in the root systems. This conclusion points up the need for an applied disease and insect integrated pest management approach to controlling the SPB and other pests of the southern pine forest.

Piedmont

Georgia

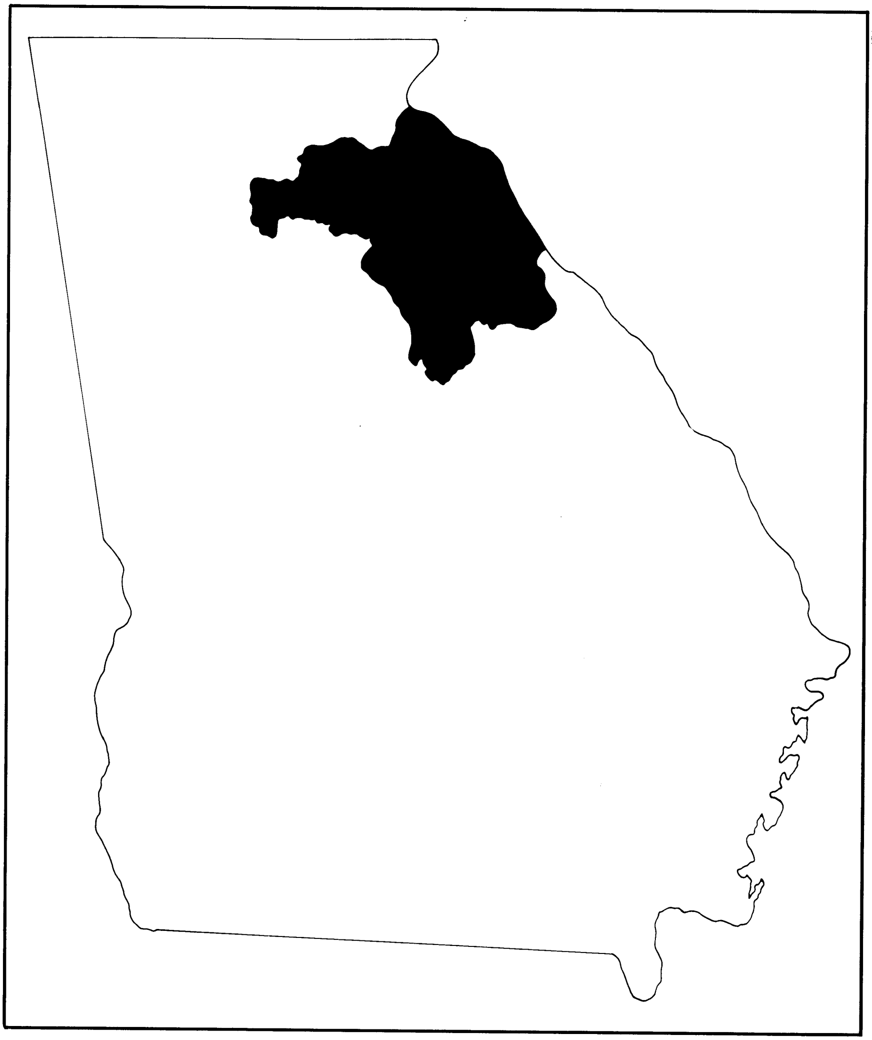
Roger P. Belanger

Study Area

The Piedmont of Georgia can be divided into two distinct physiographic regions. The lower Piedmont has broad interstream areas of gently rolling hills. The upper Piedmont is characterized by hilly topography with pronounced ridges. At one time most of this land was in clean-cultivated crop production. Depletion of the soil by continuous cropping and severe erosion resulted in widespread land abandonment. The more severe sites have reverted back to forests. The better soils are still in agriculture.

SPB outbreaks, spread, and impact have historically been most severe in the upper Piedmont. Study plots were located in Banks, Clarke, Elbert, Forsyth, Franklin, Green, Hall Hart, Jackson, Madison, Oconee, Oglethorpe, Stephens, and Wilkes Counties (fig. 11). Loblolly pine and shortleaf pine represent approximately 97 percent of the natural pine component in this area. The remaining 3 percent is mostly Virginia pine (*Pinus virginiana* Mill). Predominant soil types are slick red subsoils formed from micaceous rocks, and heterogeneous soils formed from a mixture of acid and basic crystalline rocks.

Study plots were installed in 1975 through 1977. SPB populations during 1975 were declining from epidemic conditions and the populations were generally endemic during 1976 and 1977. Most of the study plots were located on nonindustrial private lands. One field



crew did all installations and soil analyses.[1]

Figure 11.—Study area in the upper Piedmont of Georgia.

[1]Edward J. Porterfield and Robert J. Pittard are gratefully acknowledged for their exceptional work in the field and laboratory.

Results and Discussion

Stands attacked by SPB are characterized by slower radial growth, a higher percentage of clay in the surface and subsurface horizons, and a deeper surface soil depth than baseline plots (table 37). The two study populations differed only slightly in amount of pine BA, age, site index, or bark characteristics. The hardwood component and amount of understory vegetation were significantly less for attacked plots than baseline plots. Collectively, these two components could alter stand conditions or beetle behavior in a manner that reduces the susceptibility of stands to SPB attack. Belanger and others (1979) found that infestations in the mountains of Georgia were more prevalent in pure pine stands than in stands with a mixture of pine and hardwood.

Table 37.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—Georgia Piedmont

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0-5 yrs ago
Avg. radial growth 6-10 yrs ago

*Mean and standard deviation for those plots with nonzero slope and aspect. Eighty-three percent of the attacked stands had no slope.

Units	Attacked plots (122)		Baseline plots (140)	
	Mean	SD	Mean	SD
%	11.6	6.5	11.3	4.6
degree	196.1	98.9	190.8	107.3
%	56.4	10.5	60.6	12.2
%	18.9	5.5	20.6	7.5
%	24.7	9.2	18.8	9.4
$\log \frac{1}{[H^+]}$	5.1	0.3	5.1	0.3
cm	10.7	6.3	7.0	5.4
%	40.7	12.3	42.0	13.5
%	17.1	5.4	19.0	7.7
%	42.1	12.1	39.0	13.5
$\log \frac{1}{[H^+]}$	5.2	0.2	5.3	0.3
ft^2/acre	100	34.3	101	3.9
ft^2/acre	17	20.0	24	25.4
ft^2/acre	118	32.3	124	40.9
%	50	20.7	57	19.1
years	34	12.8	35	14.2
trees/acre	675	508.5	773	940.1
ft	75.7	114.1	72.2	11.9
number	45.6	79.5		
in	0.5	0.1	0.6	0.1
in	0.9	0.2	0.9	0.2
mm	11.5	4.4	14.1	5.6
mm	15.1	6.0	18.0	9.1

Table 38.—Landform classification of attacked and baseline plots in natural, undisturbed stands—Georgia Piedmont

Landform	Attacked (122)	Baseline (140)
	Percent	
1. Flood plain		0.7
2. Stream terrace	4.0	5.7
3. Upland flat	3.3	5.7
4. Ridge	32.0	49.3
5. Steep side slope	60.7	38.6
	100.0	100.0

More than 60 percent of infested stands were located on steep side slopes (slopes $\geqq$ 10 percent). Ridge tops and gentle slopes are characteristic of the baseline plots (table 38). Soil types are closely associated with landforms in the Piedmont. Soils with high proportions of sand are generally found on flat areas where erosion has been minimal. Clay loams are characteristic of slopes from which much of the topsoil has been removed by erosion. These micaceous clay soils have a high erosion potential and require careful tending.

Heavy stocking was common on both attacked and baseline plots (table 39). Basal areas $\geqq$ 110 ft^2/acre occurred on 64 percent of the attacked plots and 66.5 percent of the baseline plots.

The most striking difference between attacked and baseline plots is the proportion of the pine component in shortleaf and loblolly pine. Attacked stands were predominantly shortleaf pine (68.6 percent), whereas baseline plots contained mostly loblolly pine (55.5 percent).

Table 39.—Basal area class of attacked and baseline plots in natural, undisturbed stands—Georgia Piedmont

Basal area class	Attacked (122)	Baseline (140)
ft^2/acre	Percent	
< 50	0.8	1.4
50–70	8.2	10.7
80–100	27.0	21.4
110–130	37.0	27.9
140–160	23.8	22.9
170–190	1.6	12.1
200–220	1.6	3.6
	100.0	100.0
Average BA in ft^2/acre	117.6	124.3
Average percent pine	85.5	81.0
Percent of pine component in:		
Shortleaf	68.6	44.5
Loblolly	31.4	55.5

Table 40.—Size and frequency distribution of infestations in natural, undisturbed stands—Georgia Piedmont (n = 122)

Acres (nearest 0.25 ac) Lower limit	Acres (nearest 0.25 ac) Upper limit	Percent of total
0.00	0.25	54.1
0.50	1.00	36.9
1.25	2.00	7.4
2.25	10.00	1.6
		100.0

More than 90 percent of the attacked spots were $\leqq$ 1.0 acre in size; 54 percent were $\leqq$ 1/4 acre in size (table 40). The small spot spread could be related to the decline in number of beetles during the study period and/or the heterogeneous patterns of forest stands, soils, and sites in the Piedmont.

Stands infested by SPB in the upper Piedmont of Georgia usually have a large percentage of the host component in shortleaf pine, a high clay content in the surface and subsurface horizons, and slow radial growth during the last 10 years. These variables must be considered collectively in ascertaining a possible cause-and-effect relationship.

Inherently, shortleaf pine has a shallow root system. Poor percolation and inadequate aeration in clay soils further restrict expansive root development. These conditions can also lead to the onset of root diseases and the killing of fine roots. Deteriorating root systems cause a sustained reduction in radial growth.

Physiological stress on trees and stands can be severe during periods of drought or excess moisture. "Locus" trees—those first attacked and preferred by SPB—appear to be dominant and codominant trees with large live crown ratios and root systems in incipient stages of decline. Trees in advanced stages of decline are seldom killed by SPB. Moisture and nutrient supply in these trees may not be adequate for successful attack or brood production.

Many of the site, stand, and host tree characteristics associated with SPB infestations in the Piedmont of Georgia can be recognized or measured readily in the field. Cultural treatments should be scheduled for high-hazard stands to reduce or eliminate timber losses from SPB.

North Carolina

T. E. Maki, D. W. Hazel, and J. R. Hall

Study Area

Plots were located in forests adjacent to Kerr Reservoir in Vance County, North Carolina (fig. 12). The physiographic character of the area is typical of the Southern Piedmont, with long, rolling hills and well-developed valleys and stream channels.

Forests occupy roughly two-thirds of the land in counties around Kerr Reservoir. About 70 to 80 percent of the commercial forest land is in farm and miscellaneous private individual ownerships. The levels of forest management vary tremendously, from extensive to none.

A narrow zone of forest land around Kerr Reservoir has been flooded several times during recent years. The most severe floods (June-July 1972, April 1975, and May 1978) inundated as much as 20,000 acres of upland forests, causing heavy damage to most hardwood species.

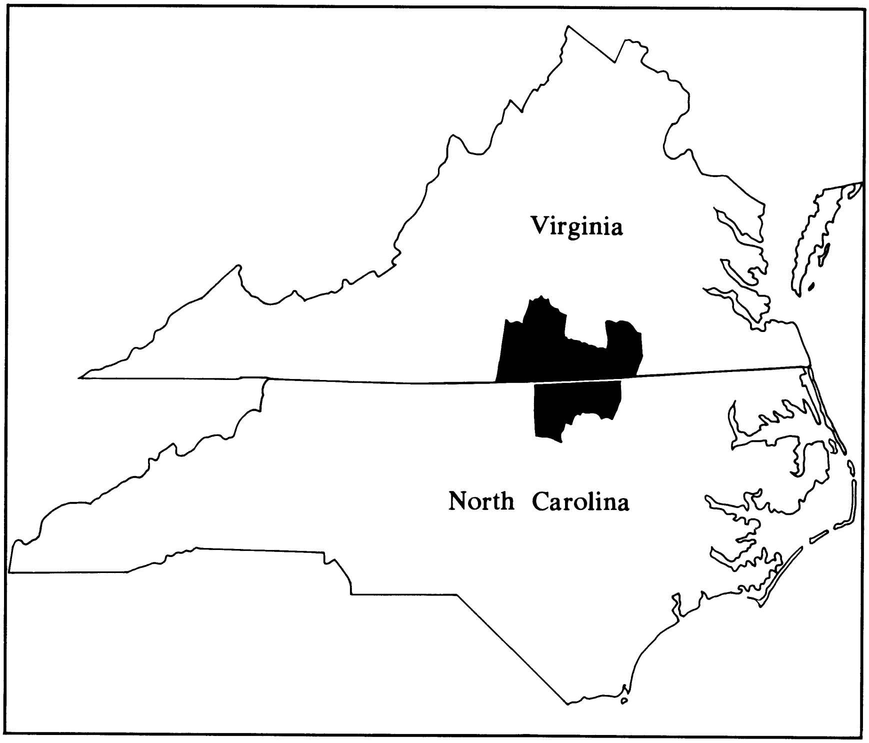


Figure 12.—Study area in the Piedmont of North Carolina.

Results and Discussion

Site/Stand Variables.—A total of 163 plots were established. Unattacked plot data came from nearby control plots. Comparing the means, we found that the SPB plots and control plots were not greatly different, at least for many factors thought to be associated with stand susceptibility (table 41). Values for pine BA, hardwood BA, slope, stand age, stand understory, stand density, site index, average d.b.h., and bark thickness at ridge and fissure were similar in both attacked and unattacked stands. There is a slight trend, however, for higher radial growth rates in unattacked stands.

Comparisons of soil characteristics between attacked and control plots revealed few major differences in the subsurface soils (table 41). However, percentage of sand and silt in the surface soils differed significantly ($P \leqq .05$) between control and attacked plots. Control plots were on soils with a higher proportion of sand in the top 15 cm. This prevalence of sand was further seen in the surface soil textural classes for attacked and unattacked plots; 88 percent of the control plots were on loamy sands and sandy loams, while only 59 percent of the attacked plots were the same two textural classes.

Table 41.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—North Carolina Piedmont

Variable
Slope*
Aspect*
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Stand understory
Age
Density
Site index at 50 yrs
SPB-killed trees
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago

*Mean and standard deviation for those plots with nonzero slope and aspect. Eighty-three percent of the attacked stands had no slope.

Units	Attacked plots (86)		Baseline plots (36)	
	Mean	SD	Mean	SD
%	7.5	6.3	8.0	7.7
degree	197.8	101.4	198.0	100.8
%	54.5	18.7	58.6	15.1
%	32.2	14.9	27.8	10.6
%	14.3	9.8	13.5	6.4
$\log \frac{1}{[H^+]}$	5.0	0.4	5.2	0.4
cm	17.7	7.7	17.7	6.1
%	35.5	15.6	36.6	15.2
%	30.6	9.7	28.2	8.9
%	33.9	11.7	35.2	11.7
$\log \frac{1}{[H^+]}$	5.2	0.4	5.4	0.4
ft^2/acre	128	34.3	134	32.5
ft^2/acre	25	26.9	23	23.3
ft^2/acre	154	39.1	157	36.4
%	62	30.0	61	27.2
years	37	14.0	37	17.0
trees/acre	894	735.3	858	601.6
ft	79.7	9.1	81.3	11.8
number	860	1454.8		
in	0.3	0.7	0.3	0.5
in	0.6	0.2	0.7	0.1
mm	8.6	3.7	9.1	3.3
mm	10.2	5.0	10.4	3.6

Table 42.—Landform classification of attacked and control plots in natural, undisturbed stands—North Carolina Piedmont

Landform	Attacked (86)	Control (36)
	Percent	
1. Flood plain		
2. Stream terrace		
3. Upland flat	28.0	29.0
4. Side slope		
5. Steep side slope	5.8	14.2
6. Ridge	66.2	56.8
7. Other		
	100.0	100.0

An examination of attacked and control plots reveals a higher percentage of attacked plots occurring on ridges while a lower percentage of attacked plots occurred on steep side slopes (table 42). The absence of plots on side slopes probably represents the field crews' failure to differentiate between side slope and steep side slope. Similar inconsistencies in field-crew performance in estimating landform were reported by Hicks et al. (1978).

Table 43.—Disturbance categories of attacked and control plots—North Carolina Piedmont

Disturbance	Attacked (109)	Control (54)
	Percent	
1. No known disturbance	87.2	77.8
2. Logging activity within previous yr		
3. Logging activity more than 1 yr ago	10.0	22.2
4. Ice and/or hail damage, severe—over one-half of stems affected		
5. Ice and/or hail damage, light—less than one-half of stems affected		
6. Fire within previous yr		
7. Fire more than 1 yr ago		
8. Lightning strike evident	2.8	
9. Chem. brush control within previous yr		
10. Chem. brush control more than 1 yr ago		
11. Wind damage		
12. Other		
	100.0	100.0

About 13 percent of the attacked plots were associated with stand disturbances, whereas 22 percent of the control plots were disturbed (table 43). Old logging activity ($\geqq 1$ year ago) occurred in control plots at about twice the frequency it occurred in attacked plots. Lightning strikes were found only in attacked plots.

Table 44.—Basal area class of attacked and control plots in natural, undisturbed stands—North Carolina Piedmont

Basal area class	**Attacked (86)**	**Control (36)**
ft²/acre	Percent	
<50		
50–70		
80–100	9.3	2.8
110–130	25.6	25.0
140–160	29.0	38.9
170–190	24.4	22.1
200–220	5.8	5.6
230–250	4.7	2.8
≧260	1.2	2.8
	100.0	100.0
Average BA in ft²/acre	153.6	156.9
Average percent pine	83.3	85.5

Table 45.—Size and frequency distribution of infestations in natural, undisturbed stands—North Carolina Piedmont (n = 109)

Acres (nearest 0.25 ac)		**Percent of total**
Lower limit	Upper limit	
0.0	0.25	38.5
0.5	1.0	20.2
1.25	2.0	8.3
2.25	10.0	24.8
10.25	20.0	1.8
20.25	50.0	5.5
50.25	+	0.9
		100.0

Distribution of plots by BA class appears similar for attacked and control plots (table 44). In both cases, however, mean stand density was high, although the distribution is more closely grouped about the mean for unattacked stands. The mode is about the same for both (140–160 ft²/acre class).

Table 45 indicates that 38.5 percent of infestations were < 1/4 acre in size, yet more than 30 percent of infestations covered > 2 acres. The mean size of infestations was 4.9 acres.

Table 46.—Pine species by tree status,on attacked plots—North Carolina Piedmont

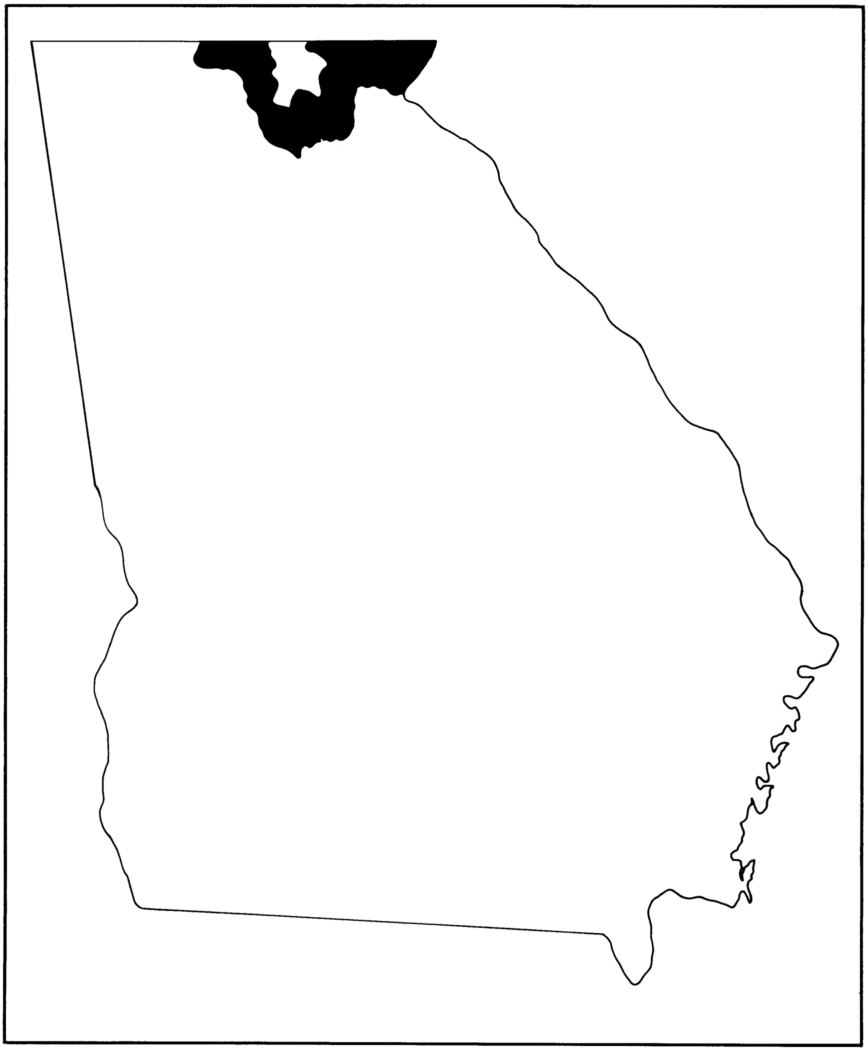
	Pine Species	Tree Status				
		Dead	**Live**	**Survived attack**	**Dead—unknown**	**Total**
Frequency row %	Loblolly	211 71.0	84 28.3	2 0.7	0 0.0	297
	Shortleaf	832 83.1	153 15.3	14 1.4	2 0.2	1001
	Virginia	36 48.0	16 21.3	23 30.7	0 0.0	75
	Totals	1079	253	39	2	1373

A contingency table of pine species by tree status (table 46) demonstrates the relative susceptibility of loblolly, shortleaf, and Virginia pine to SPB. The χ^2 test was significant, indicating interaction of tree species and tree status. Of 297 loblolly pines on attacked plots, 71 percent were attacked. Of the shortleaf pines, 83 percent were attacked while only 48 percent of the Virginia pines were attacked. The survived attacked category is also of interest. Trees in this category had evidence of previous attack by SPB (pitch tubes, etc.) but were apparently living when the plots were established. About 31 percent of the Virginia pines had survived attacks, whereas only about 1 percent of loblolly and shortleaf pines did so.

The evidence suggests that, in the Piedmont, shortleaf pine is more prone to attack by SPB and to death when attacked. One reason for shortleaf's apparent susceptibility may be the possibility of association with incipient presence of littleleaf disease (*Phytophthora cinnamoni*). Many shortleaf pines show signs of littleleaf, especially those close to water.

Georgia Mountains

R. P. Belanger and G. E. Hatchell



Study Area

Stand, site, and soil conditions were studied from 1975 through 1977 in the mountains of northeast Georgia. The survey included all or parts of Fannin, Lumpkin, Rabun, Towns, and White Counties (fig. 13). All attacked plots occurred in natural stands, and most were in National Forests. SPB populations during 1975 were in decline from epidemic conditions; populations were generally endemic during 1976 and 1977.

Figure 13.—Study area in the Mountains of northeast Georgia.

Additional Procedures

Forest Service inventory statistics were used as baseline data to characterize representative forest types and conditions.[1] These baseline data came from the same counties as attacked plots.

Results and Discussion

Plots attacked by SPB in the mountains of Georgia (table 47) were older and more heavily stocked than stands representative of the area (table 48). Baseline stands averaged 33 years of age and contained 103 ft^2 of pine and hardwood BA per acre. Attacked plots averaged 62 years of age and supported 129 ft^2 of stocking per acre. More than 80 percent of the attacked plots had BA > 100 ft^2/acre (table 49). Woody understory vegetation covered an additional 67 percent of the area in the lower canopy. This is extremely high density for site index 66 lands to support.

The high BA associated with attacked plots is reflected in the slow growth rate of the pine overstory. Radial growth on dominant and codominant trees averaged 16.7 mm during the last 10 years and 7.7 mm during the last 5 years. These mature stands are in an obvious state of decline.

Comparisons between attacked plot data and baseline data indicate that SPB more frequently attacked shortleaf pine and pitch pine (*Pinus rigida* Mill.). Shortleaf pine areas accounted for 59 percent of the infestations; 23 percent occurred in the pitch pine type (table 50). Yet these two species represent only 29 and 6 percent of the total pine component in the area. Virginia pine is the dominant pine species in the mountains of Georgia. A small percentage of the infestations occurred in this type. No SPB infestations were located in eastern white pine (*Pinus strobus* L.) stands. These levels of susceptibility between species were also evident from examination of individual tree characteristics (Belanger et al. 1979).

More than 90 percent of the infestations were < 1 acre in size; 54 percent were $< 1/4$ acre in size (table 51). The small sizes could be related to the decline in number of beetles during 1976 and 1977, and/or the heterogeneous patterns of forest stands and sites in the mountains. The largest infestation studied—20 acres—occurred in a shortleaf pine and pitch pine mixture during a peak period of beetle activity.

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[1]Information supplied by Renewable Resources Evaluation, USDA For. Serv., Asheville, N.C. Data collected July–September 1972.

Table 47.—Site and stand characteristics of attacked plots in natural, undisturbed stands—Georgia Mountains

Variable	Units	Attacked plots (22)	
		Mean	SD
Slope	%	24.9	10.3
Aspect	degree	161.6	92.7
Surface sand	%	53.6	11.9
Surface silt	%	53.6	7.2
Surface clay	%	27.0	9.9
Surface pH	$\log \frac{1}{[H^+]}$	4.7	0.3
Surface soil depth	cm	13.5	6.4
Subsoil sand	%	44.0	14.7
Subsoil silt	%	18.5	6.0
Subsoil clay	%	37.5	12.2
Subsoil pH	$\log \frac{1}{[H^+]}$	5.0	0.2
Pine BA	ft^2/acre	92	31.1
Hdwd. BA	ft^2/acre	37	20.3
Total BA	ft^2/acre	129	34.5
Stand understory	%	67	21.5
Age	years	62	19.0
Density	trees/acre	658	597.6
Site index at 50 yrs[1]	ft	66	5.8
SPB-killed trees	number	42.8	68.1
Avg. bark—fissure	in	0.5	1.0
Avg. bark—ridge	in	0.8	0.2
Avg. radial growth 0–5 yrs ago	mm	7.7	3.3
Avg. radial growth 6–10 yrs ago	mm	9.0	3.5

[1]Based on height of shortleaf pine.

Table 48.—Basal areas and age of baseline plots—Georgia Mountains

Variable	Units	Baseline
		Mean
Pine BA	ft^2/acre	76
Hdwd. BA	ft^2/acre	27
Total BA	ft^2/acre	103
Age	years	33

Table 49.—Basal area class of attacked plots in natural, undisturbed stands—Georgia Mountains

Basal area class	Attacked (22)
ft^2/acre	Percent
50–70	13.6
80–100	4.6
110–130	31.8
140–160	40.9
170–190	9.1
	100.0
Average BA in ft^2/acre	128.6
Average percent pine	71.4

Table 50.—Pine types of attacked and baseline plots—Georgia Mountains

Pine type*	Attacked	Baseline
	Percent	
Shortleaf	59	29
Virginia	9	55
Pitch	23	6
Eastern white		10
Loblolly	9	
	100	100

*Stands in which one species represents 70 percent or more of the crowns in the dominant and codominant positions.

Table 51.—Size and frequency distribution of infestations in natural, undisturbed stands—Georgia Mountains

Acres (nearest 0.25 ac)		Percent of total
Lower limit	Upper limit	
0.00	0.25	54.5
0.50	1.00	36.5
1.25	2.00	4.5
10.00	20.00	4.5
		100.0

Table 52.—Landform classification of attacked plots in natural, undisturbed stands—Georgia Mountains

Landform	Attacked (22)
	Percent
1. Bench	4.6
2. Cove	22.7
3. Northerly aspect slopes — <2500 ft	13.6
4. Southerly aspect slopes — <2500 ft	18.2
5. Southerly aspect slopes — 2500-4500 ft	22.7
6. Ridge and upper slope — <2500 ft	13.6
7. Ridge and upper slope — 2500–4500 ft	4.5
	100.0

Soils on the study plots were formed from predominantly mica and mafic parent materials. Laboratory analyses indicate that the average texture of the surface horizon from 0 to 6 inches is sandy clay loam and the B horizon is sandy clay. Average depth of the A horizon was 13.5 cm. Attacks were noted across a wide range of landforms (table 52). More infestations occurred on southerly aspects than northerly aspects. South-facing slopes are where most of the pines occur in the Southern Appalachians.

Stands attacked and killed by the southern pine beetle in the Mountains of Georgia were characterized by dense stocking, slow radial growth, and overmature, predominantly pine species. Although silvicultural techniques offer means of reducing pine mortality from beetle attacks (Belanger et al. 1979), accessibility of stands, market conditions, and stumpage values often prohibit the intensive management of these problem locations. Primary emphasis should be given to high-risk stands that contribute significantly to management objectives.

Characteristics of Southern Pine Beetle Infestations Southwide

Richard L. Porterfield and
Charles E. Rowell

Substantial areas within the range of SPB are not represented by the seven preceding projects. If there are factors in common among infestations throughout a subregion, or even in common between subregions, then there is justification for extending recommendations based on these data to wider areas. What follows is an analysis of the ESPBRAP/Coordinated Regional Project data on a geographic subregion basis in order to provide a Southwide characterization of factors associated with SPB infestations.

The data are pooled across projects for this analysis; and, as might be expected, project-to-project differences are important for a number of site/stand variables. However, these differences are significantly reduced and in some cases disappear altogether when all projects are compared on a uniform basis. For example, project-to-project differences are greatly reduced when a particular landform, such as upland flats in the Coastal Plain, is examined across projects. The reliability of measurements of the standard data set among various project crews is expected to be good (Hicks et al. 1978).

Coastal Plain

Most of the SPB data were collected in the Coastal Plain subregion. Investigators established some 2,021 plots at SPB infestations and another 1,092 baseline plots in uninfested stands to provide a representation of general forest conditions. Coastal Plain plots were established, almost exclusively, in the mid-South region: Texas, Louisiana, Arkansas, and Mississippi. Fewer than 60 plots were available from the North Carolina and Virginia Coastal Plains; however, these plots do resemble those from the mid-South.

In all, 92 percent of the SPB plots and 95 percent of the baseline plots were established in naturally occurring stands (table 53). If present, various disturbances such as ice damage or recent harvesting were recorded at time of plot establishment; this breakdown is also provided in table 53. Table 54 shows the distribution of plots by specific type of disturbance for natural stands. Although most disturbances seem unrelated to SPB attacks, it is quite evident that lightning strikes do predispose stands to beetle activity. In the Coastal Plain SPB plots, 23 percent evidenced recent lightning strikes, while such strikes occurred only 1 percent of the time in the baseline sample.

Table 53.—Distribution of Coastal Plain plots by infestation status, stand origin, and disturbance category

	Stand Origin	
	Natural	Plantation
SPB-attacked		
Disturbed	1082	74
Undisturbed	779	86
Baseline		
Disturbed	477	23
Undisturbed	560	32
Total	2898	215

Table 54.—Disturbance categories of attacked and baseline plots in natural stands—all Coastal Plain projects

Disturbance	Attacked (1082)	Baseline (477)
	Percent	
1. No known disturbance	42	54
2. Logging activity within previous yr	12	8
3. Logging activity more than 1 yr ago	10	21
4. Ice/hail damage, severe—over one-half of stems affected	1	0
5. Ice/hail damage, light—less than one-half stems affected	5	4
6. Fire within previous yr	1	2
7. Fire more than 1 yr ago	2	7
8. Lightning strike	23	1
9. Chem. brush control within previous yr	0	0
10. Chem. brush control more than 1 yr ago	0	1
11. Wind damage	2	1
12. Other	2	1
	100	100

Another factor apparent in table 54 and consistent across individual projects is the impact of logging activity. Recent logging (within the year) has a tendency to increase SPB attack, but stands harvested earlier (1 to 5 years ago) are significantly less attacked. It appears that recent logging damage makes conditions more favorable for SPB, but once the residual trees begin to respond to growing conditions in the thinned stand, the trees may become less susceptible to attack. This relationship points out the merits of careful logging and hints at the longer-term benefits of reduced BA. Reducing understory competition through the use of fire may also increase resistance once the trees respond (table 54). The plantation data are not adequate for detailed analysis; however, 54 percent of the infestations in plantations were undisturbed and 23 percent of all disturbances recorded were lightning strikes.

Table 55 documents the characteristics of Coastal Plain infestations. These statistics cover only natural, undisturbed stands in order to eliminate the possibility that disturbances may predispose the stand to attack regardless of existing site/stand conditions. The average value for slope reflects the occurrence of extensive, nearly level areas in the Coastal Plain. Where some slope does occur, attacked stands most often have a southerly exposure; the standard deviation for aspect indicates this trait is quite varied, however.

The A horizon (surface soil depth) of sites with SPB attacks is adequate for good root mass, and both the surface soil and subsoil have significant sand components. Soil pH is low. Of the total BA on plots established at SPB infestations, 80 percent is pine (table 55). Average total BA is high, given the average age of 40 years.

The 50 percent understory occupation by woody stems (table 55) suggests that the average infestation is a pine stand with a small-diameter hardwood understory. This deduction is supported by other facts also: the average age is 40 years, and though there are some 764 stems per acre, only 263 of these are over 4.6 inches at breast height.

Measurements of pine volume were derived using a single southern pine volume equation developed for a wide range of d.b.h. and height combinations (MacKinney and Chaiken 1939). Tree volumes for "in" trees on the BA plot were converted to a per-acre basis and summed (table 55). These volume figures, both total and sawtimber size only, should probably be treated as indices of actual volume, because the single equation was applied across the South. Obviously, there is substantial variation in total stand volume of pine and in the sawtimber component. The coefficient of variation for sawtimber volume is 70 percent. Using 4.0 fbm/ft^3 (Williams and Hopkins 1968), the Doyle volume is approximately 7,900 fbm/acre in these infested stands.

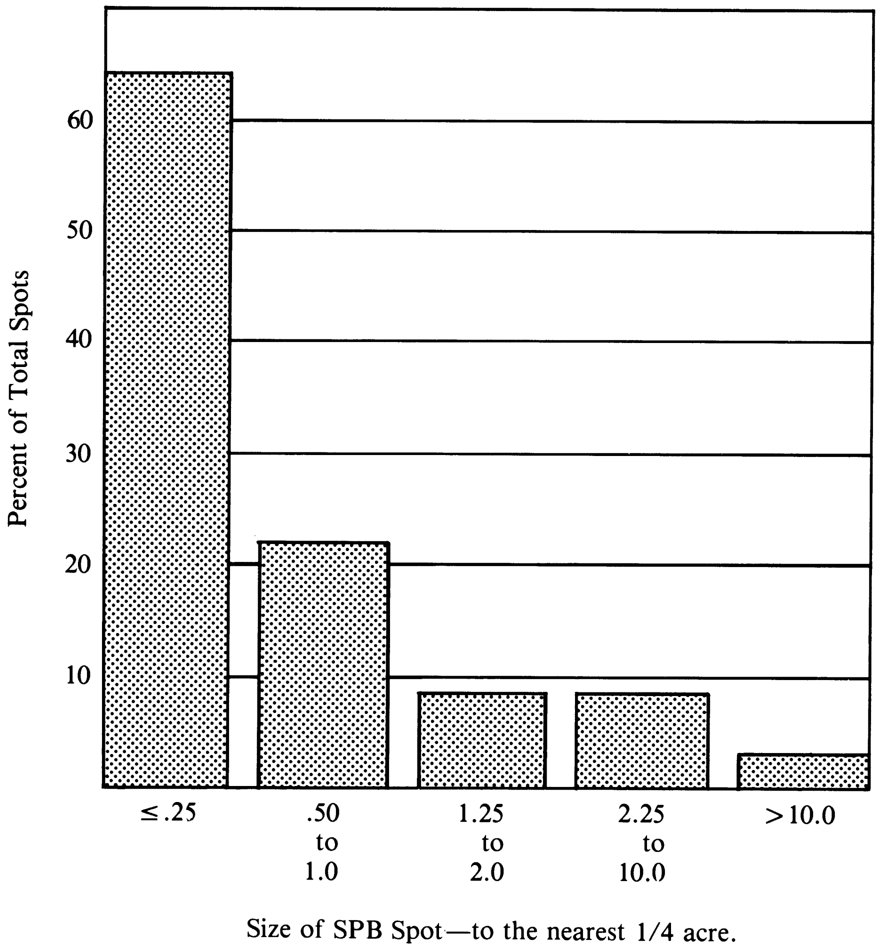
Table 55.—Site and stand characteristics of attacked plots in natural, undisturbed stands—all Coastal Plain projects (n = 779)

Variable	Units	Mean	SD
Slope	%	3.2	5.0
Aspect	degree	186.1	110.1
Surface sand	%	58.1	18.6
Surface silt	%	31.7	15.4
Surface clay	%	10.4	7.1
Surface pH	$\log \frac{1}{[H^+]}$	5.0	0.5
Surface soil depth	cm	36.4	22.3
Subsoil sand	%	45.6	18.4
Subsoil silt	%	30.4	14.0
Subsoil clay	%	24.1	13.4
Surface pH	$\log \frac{1}{[H^+]}$	4.9	0.5
Pine BA	ft^2/acre	110	42.0
Hrdwd. BA	ft^2/acre	26	24.2
Total BA	ft^2/acre	137	43.9
Understory	%	50	27.0
Age	years	40	15.4
Density—all stems	trees/acre	764	1046.3
Density—stems > 4.6 inches d.b.h.	trees/acre	263	144.1
Site index at 50 yrs	ft	85.3	14.6
Avg. bark—fissure	in	0.3	0.2
Avg. bark—ridge	in	0.9	0.3
Avg. radial growth 0–5 yrs ago	mm	15.3	6.0
Avg. radial growth 6–10 yrs ago	mm	21.7	13.5
Avg. stand d.b.h. pine	in	8.9	4.0
Avg. height—pine	ft	58.6	20.3
Live crown ratio	%	58.6	20.3
Total stand volume—pine[1]	ft^3/acre	2758.6	1401.4
Total sawtimber volume—pine[2]	ft^3/acre	1974.5	1382.2

[1]Volume in pine trees with d.b.h. $\geqq$ 4.6 in.
[2]Volume in pine trees with d.b.h. $\geqq$ 9.6 in.

Volume equation (MacKinney and Chaiken 1939):

$$\log_{10} (ft^3 \text{ volume}) = 1.9557 (\log_{10} \text{d.b.h.}) + 1.0971 (\log_{10} \text{total ht.}) - 2.8209$$



The average size of SPB infestations is small (fig. 14); 63 percent were estimated to cover < 1/4 acre, and not all the trees within this area were killed by SPB. SPB-killed trees were often scattered within the spot. Nearly all (95 percent) of the infestations were considered inactive at time of measurement. Some 32 percent of them contained 10 or fewer SPB-killed trees, and 53 percent consisted of 25 SPB-killed trees or fewer. Number of SPB-killed trees per infestation was significantly positively correlated with stand BA and stand cubic-foot volume.

Figure 14.—Spot size for natural, undisturbed Coastal Plain SPB infestations.

Table 56.—Landform classification of attacked and baseline plots in natural, undisturbed stands—all Coastal Plain projects

Landform	Attacked (779)	Baseline (560)
	Percent	
1. Swamp	1	0
2. Flood plain	8	3
3. Stream terrace	5	6
4. Bay	3	3
5. Upland flat	47	38
6. Lower slope	8	7
7. Side slope	12	34
8. Steep side slope	2	4
9. Ridge	14	5
	100	100

In addition to the variables listed in table 55, the investigators recorded several descriptive characteristics associated with each infestation. These included landform, soil texture, source of soil material, water regime, modifiers, and accessory characteristics. These variables were coded according to the *Soil Resource Guide, Southern Region* (USDA Forest Service 1972). Foremost in importance with regard to these variables is landform.

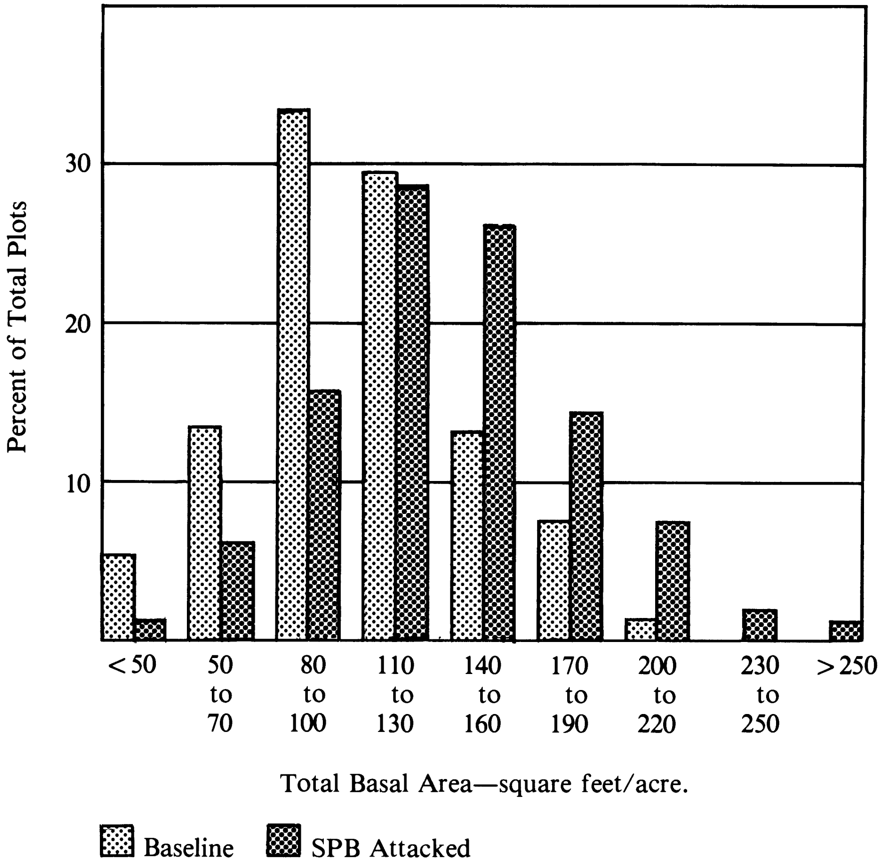
Table 56 shows the distribution of SPB-attacked and baseline plots, according to landform classification. The landform titles provided are descriptive, but a full definition can be found in the *Soil Resource Guide.* Assuming that the baseline plots compose a representative sample of general forest conditions, there are significant differences (by χ^2 test at $P = 0.05$) in number of SPB infestations by landform (table 56). Side slopes had fewer SPB attacks. Flood plains and upland flats are subject to flooding; stands on these landforms are more likely to experience temporary moisture stress due to lack of normally available rooting area (Lorio and Hodges 1971). Ridges—the upper part or crests of broad interstream divides—tend to dry out quickly in periods of low rainfall, thus increasing water stress on the pines. Ridges are also often associated with lightning strikes.

Table 57.—Site and stand characteristics that differ significantly between attacked and baseline plots in natural, undisturbed stands[1]—all Coastal Plain projects

Variable	Units	Mean		Sign. Level
		Attacked (779)	Baseline (560)	
Slope	%	3.2	6.5	0.01
Subsoil silt	%	30.4	27.1	0.01
Pine BA	ft^2/acre	110	72	0.01
Hardwood BA	ft^2/acre	26	37	0.01
Total BA	ft^2/acre	137	109	0.01
Site index at 50 yrs	ft	85.3	30.5	0.01
Avg. bark—fissure	in	0.3	0.3	0.01
Avg. bark—ridge	in	1.0	0.9	0.01
Avg. radial growth 0–5 yrs ago	mm	15.3	18.1	0.01
Avg. stand d.b.h.	in	8.9	9.6	0.01
Avg. live crown ratio	%	36.3	40.5	0.01
Total stand volume—pine	ft^3/acre	2758.6	1496.9	0.01
Total sawtimber volume—pine	ft^3/acre	1974.5	1155.5	0.01
Age	years	39.5	41.4	0.05

[1]See Table 55 measurement units.

Table 57 records site/stand variables that differed significantly between attacked and baseline plots. Some of these variables may be useful from the resource manager's perspective; others do not appear to be. Attacked plots typically occurred on sites that were flatter, had higher BA and correspondingly greater volume, and were slower growing. These traits are dependable discriminating characteristics in nearly every situation. The differences in average age and site index are not adequate to explain the higher BA and volumes in the attacked plots (fig. 15).



Fifty percent of the infestations had BA over 130 ft²/acre, while almost 80 percent of the baseline plots had BA of 130 ft²/acre or less. Total stand volume, pulpwood and sawtimber-sized material, on infested sites was 185 percent of the comparable baseline figure (2,759 *v.* 1,497, table 57). In addition, SPB-attacked stands were 80 percent pine on the basis of BA, whereas the baseline stands were only 66 percent pine. These statistics reflect a stand composition difference as well as a total BA difference between attacked and baseline stands.

Thinning could, perhaps, reduce the susceptibility of dense stands. Assuming 75 ft³/cord, removal of one-third of the total volume of SPB-attacked stands as pine pulpwood would yield over 12 cords/acre, some of which could be saw-

Figure 15.—Distribution of natural, undisturbed Coastal Plain stands by infestation status and basal area classification.

timber. And this figure ignores the hardwood volume that could be removed. Such a thinning would still leave an operable pine BA of between 75 and 80 ft^2/acre plus whatever hardwood was not removed.

Such a thinning would reduce per-acre volume and BA (especially if hardwoods were removed) and, with time, increase growth rate and improve live crown ratios. All of these changes would tend to reduce the incidence of SPB attack (table 57). Since stand characteristics are more closely associated with SPB attacks in the Coastal Plain, the resource manager can reduce the incidence of SPB attacks through modification of stand conditions and basic stand management systems. Even the use of controlled burning to reduce small-hardwood competition would be useful.

The little data available for SPB-attacked and baseline plantations in the Coastal Plain indicate that attacked and unattacked plantations are quite similar. Slope and radial growth are the only variables of explanatory importance, and they behave in a manner similar to natural stands. Baseline plantations are on sites with an average slope of 4.8 percent (*v.* 2.4 for SPB-attacked plots) and average 47.9 mm of radial growth in the last 10 years (*v.* 40.3 for SPB-attacked plots). Pine volume, BA, stand density, and site index are very similar for attacked and baseline plots for the Coastal Plain plantation data.

Piedmont

Infested stands were sampled in Georgia, Virginia, and a small region of intense SPB activity surrounding the Kerr Reservoir in the north central part of North Carolina. Fewer plots were established in the Piedmont subregion (table 58) than in the Coastal Plain.

Eighty-five percent of the SPB-attacked data came from natural stands (table 58). While 58 percent of attacked natural stands in the Coastal Plain were disturbed, a disturbance was recorded on only 9 percent of attacked natural stands in the Piedmont (table 59). The impact of lightning strikes is still evident but appears less important in the Piedmont.

The average size of Piedmont infestations is small (fig. 16), just as in the Coastal Plain. Forty-seven percent of all spots are $< 1/4$ acre in size and the average spot is < 1.0 acre. Furthermore, the average size of Piedmont spots is greatly influenced by several large spots in North Carolina. Ninety-four percent of the 30 infestations in natural undisturbed Piedmont stands > 2.0 acres in size were found in North Carolina (fig. 16). These large infestations also influenced the average number of SPB-killed trees per infestation. Using all Piedmont infestations, the average number of SPB-killed trees per infestation was 28, while the number, excluding the North Carolina data, was 9 trees per infestation. Excluding the North Carolina data, some 61 percent of the infestations contained fewer than 25 trees.

Table 58.—Distribution of Piedmont plots by infestation status, stand origin, and disturbance category

	Stand Origin	
	Natural	Plantation
SPB-attacked		
Disturbed	22	5
Undisturbed	210	36
Baseline		
Disturbed	13	5
Undisturbed	59	20
Total	304	66

Table 59.—Disturbance categories of attacked and baseline plots in natural stands—all Piedmont projects

Disturbance	**Attacked (22)**	**Baseline (13)**
	Percent	
1. No known disturbance	91	81
2. Logging activity within previous yr	0	4
3. Logging activity more than 1 yr ago	5	3
4. Ice/hail damage, severe—over one half stems affected	0	0
5. Ice/hail damage, light—less than one-half stems affected	1	0
6. Fire within previous yr	0	0
7. Fire more than 1 yr ago	0	0
8. Lightning strike	3	0
9. Chem. brush control within previous yr	0	0
10. Chem. brush control more than 1 yr ago	0	0
11. Wind damage	0	0
12. Other	0	12
	100	100

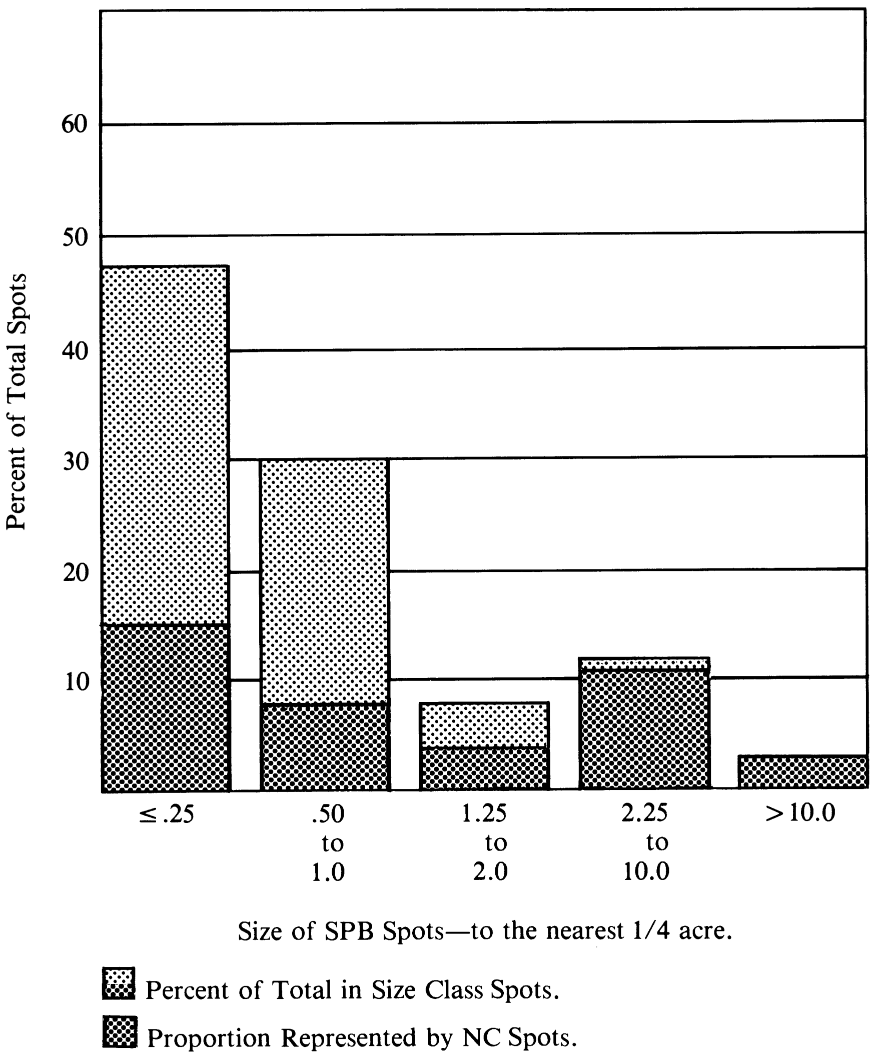


Figure 16.—Distribution of natural, undisturbed Piedmont SPB infestations by spot size.

Once again, to eliminate possible bias in the data, plots with disturbances that may predispose stands to SPB attack were deleted from consideration; only natural, undisturbed infestations are characterized in table 60.

The geographically limited area from which the North Carolina data were collected, along with the fact that about 40 percent of the attacked plots in the Piedmont were from the Kerr Reservoir area, suggest that the total Piedmont data were weighted towards conditions in this area. Inspection of the data in tables 41 and 60 reveals obvious differences in the values of certain major variables between attacked plots in North Carolina and the total Piedmont; North Carolina infestations were in stands of higher BA, somewhat higher site index, and less radial growth. Total stand volume of pine in North Carolina was computed to be 2,387 ft³/acre while it was 2,036 ft³/acre for the total Piedmont plots (table 60). Accordingly, the values for all variables were recomputed without the North Carolina plots. These values (table 60) may be more representative of attacked plot conditions in the Piedmont than the "total Piedmont" data.

Table 60.—Site and stand characteristics of attacked plots in natural, undisturbed stands—all Piedmont projects

Variable
Slope
Aspect
Surface sand
Surface silt
Surface clay
Surface pH
Surface soil depth
Subsoil sand
Subsoil silt
Subsoil clay
Subsoil pH
Pine BA
Hdwd. BA
Total BA
Understory
Age
Density—all stems
Density—stems > 4.6 inches d.b.h.
Site index at 50 yrs
Avg. bark—fissure
Avg. bark—ridge
Avg. radial growth 0-5 yrs ago
Avg. radial growth 6-10 yrs ago
Avg. stand d.b.h.—pine
Avg. height—pine
Live crown ratio
Total stand volume—pine[1]
Total sawtimber volume—pine[2]

[1]Volume in pine trees with d.b.h. $\geqq$4.6 in.
[2]Volume in pine trees with d.b.h. $\geqq$9.6 in.

Units	Total Piedmont (210)		Excluding N.C. (124)	
	Mean	SD	Mean	SD
%	9.9	6.8	11.4	6.5
degree	196.4	99.7	196.1	98.9
%	55.5	14.4	56.3	10.5
%	24.5	12.2	18.9	5.5
%	20.6	10.8	24.8	9.4
$\log \frac{1}{[H^+]}$	5.0	0.3	5.1	0.3
cm	13.6	7.7	10.7	6.2
%	38.6	13.6	40.6	12.3
%	22.6	9.9	17.2	5.4
%	38.8	12.6	42.1	12.1
$\log \frac{1}{[H^+]}$	5.2	0.3	5.2	0.2
ft^2/acre	112	36.9	101	34.6
ft^2/acre	20	23.3	17	19.9
ft^2/acre	132	40.5	117	34.4
%	54	25.5	49	21.0
years	35	13.3	34	12.7
trees/acre	762	619.1	670	506.7
trees/acre	332.8	144.3	293.9	127.3
ft	77.4	10.7	75.8	11.3
in	0.4	0.1	0.5	0.1
in	0.8	0.2	0.9	0.2
mm	10.2	4.4	11.3	4.5
mm	13.0	6.1	15.0	5.9
in	7.4	2.4	7.4	2.6
ft	48.0	12.9	46.5	13.9
%	37.4	9.3	41.1	9.4
ft^3/acre	2035.7	959.3	1797.7	844.9
ft^3/acre	961.0	868.2	865.7	785.5

Volume equation (MacKinney and Chaiken 1939):

Log_{10} (ft^3 volume) = 1.9557 ($\log_{10}$ d.b.h.) + 1.0971 ($\log_{10}$ total ht.) − 2.8209

Table 61.—Landform classification of attacked and baseline plots in natural, undisturbed stands—all Piedmont projects

Landform	Attacked (210)	Baseline (59)
	Percent	
1. Flood plain	0	0
2. Stream terrace	2	10
3. Upland flat	14	12
4. Ridge	46	61
5. Steep side slope and narrow flood plains	39	17
	100	100

Piedmont infestations occurred on sites with greater slope, higher soil clay content, and shallower surface soils than Coastal Plain infestations. Several Piedmont plots were found to have only 1.0 cm of surface soil. The pine BA in Piedmont infestations is similar to that of Coastal Plain infestations (table 60 *v.* table 55), and for Piedmont infestations the stands also appear to be at least two-tiered, as indicated by stand density. However, average tree size and volume per acre is significantly higher for the Coastal Plain infestations, as is radial growth. Using 4.0 fbm/ft^3, Piedmont infestations average between 3,400 and 3,800 Doyle fbm/acre.

Piedmont stands on stream terraces and ridges are less susceptible to attack, while stands on steep side slopes and narrow flood plains are attacked more often than baseline stands (table 61; all Piedmont baseline plots were in Georgia). Site characteristics are most helpful in explaining SPB-attacked *v.* baseline differences in the Georgia Piedmont (table 62). Specifically, soil pH and surface soil depth are important. Unlike the Coastal Plain, variables such as slope, BA, and pine volume are not significantly different on attacked plots in the Piedmont. The higher pH values associated with baseline plots, even though the differences appear small, may mean that nutrients are more available in baseline stands.

Given these results, the resource manager may not be able to reduce the incidence of SPB in natural Piedmont stands as much as in Coastal Plain stands through silvicultural treatments. Actions to promote growth rate would be somewhat helpful and loblolly pine could be favored in natural stand management, but susceptibility is linked more closely to site. It is also possible that the susceptibility of Piedmont stands could be altered through use of fertilizers to promote growth and nutrient levels, but this is largely a matter of conjecture. An extensive survey of fertilized stands conducted by Haines and others (1976) did not substantiate that fertilization decreased susceptibility of forest stands to SPB attack.

The limited amount of undisturbed plantation data in the Piedmont suggests a single principle. Baseline plots in plantations have a significantly greater ($P \leqq 0.05$) average total BA (153.5 ft^2/acre) compared to the SPB-attacked plantations (126.4 ft^2/acre). Volume is correspondingly higher for the baseline plantations. Average plantation age is 17 years for both baseline and attacked stands. These facts, plus (1) the knowledge that these loblolly plantations frequently occur on former shortleaf sites, and (2) the significant difference in site indices (70 ft attacked *v.* 80 ft baseline), suggest that SPB attacks may be associated with loblolly pine planted "off-site" and therefore in a potentially high stress situation. This possibility certainly deserves more investigation since it may directly affect plantation establishment recommendations.

Table 62.—Site and stand characteristics that differ significantly between attacked and baseline plots in natural, undisturbed stands—Georgia Piedmont

Variable
Slope
Surface clay
Surface soil pH
Surface soil depth
Subsoil pH
Pine BA
Total BA
Site index at 50 yrs
Avg. bark—fissure
Avg. radial growth 0–5 yrs ago
Avg. radial growth 6–10 yrs ago
Avg. live crown ratio
Total stand volume—pine[1]
Total sawtimber volume—pine[2]
Age

[1]Volume in pine trees with d.b.h. $\geqq$4.6 in.
[2]Volume in pine trees with d.b.h. $\geqq$9.6 in.
Volume equation (MacKinney and Chaiken, 1938):

$$\text{Log}_{10}\ (\text{ft}^3\ \text{volume}) = 1.9557\ (\log_{10}\ \text{d.b.h.}) + 1.0971\ (\log_{10}\ \text{total ht.}) - 2.8209$$

Units	Mean		Sign. Level
	Attacked (121)	Baseline (59)	
%	11.6	10.6	N.S.
%	24.7	21.1	0.05
$\log \frac{1}{[H^+]}$	5.0	5.2	0.01
cm	10.7	7.7	0.01
$\log \frac{1}{[H^+]}$	5.2	5.4	0.01
ft^2/acre	100	97	N.S.
ft^2/acre	118	118	N.S.
ft	75.7	72.0	0.05
in	0.5	0.6	0.05
mm	11.4	15.0	0.01
mm	15.1	19.7	0.01
%	41.3	41.5	N.S.
ft^3/acre	1774.3	1660.2	N.S.
ft^3/acre	841.3	889.7	N.S.
years	33.8	31.6	N.S.

Mountains

Very few plots are available to represent the Mountain subregion (table 63). These plots come from the Ouachita mountains in west central Arkansas and the Appalachians, mainly in Georgia. No comparative baseline data are available, and no plots were established in plantations. Seventy-nine percent of Mountain plots had no disturbance associated with them, and once again lightning strikes were common (table 64).

Table 65 describes Mountain infestations. The slope is steep and the exposure is generally southeast but has substantial variance. As with Piedmont infestations, the soil clay content is high. Surface soil depth averaged a respectable 18.3 cm and ranged from 3 to 56 cm.

Pine BA averaged < 100 ft^2/acre, but there is a substantial hardwood component that brings the average total BA to a level comparable with infested plots in the Coastal Plain and Piedmont (table 65 and fig. 17). Given the average site index of 73 feet, the Mountain infestations may well be overstocked. Their average age was much greater than either Coastal Plain or Piedmont infestations, even though the average d.b.h. of the pine component was similar. Smaller diameter for age reflects the much slower growth rate on these Mountain plots. Total volume was high; the stands average 60 percent of their cubic volume in material >9.6 inches d.b.h.—about 5,200 Doyle fbm/acre.

Table 63.—Distribution of Mountain plots in natural stands by infestation status, region, and disturbance category

	Ouachitas	Appalachians
SPB-attacked		
Disturbed	12	0
Undisturbed	23	22
Baseline		
Disturbed	0	0
Undisturbed	1	0
Total	36	22

Table 64.—Disturbance categories of attacked and baseline plots in natural stands—Ouachita Mountains, Arkansas

Disturbance	Attacked
	Percent
1. No known disturbance	79
2. Logging activity within previous yr	2
3. Logging activity more than 1 yr ago	0
4. Ice/hail damage, severe—over one-half stems affected	1
5. Ice/hail damage, light—less than one-half stems affected	0
6. Fire within previous yr	0
7. Fire more than 1 yr ago	0
8. Lightning strike	16
9. Chem. brush control within previous yr	0
10. Chem. brush control more than 1 yr ago	0
11. Wind damage	0
12. Other	2
	100

Table 65.—Site and stand characteristics of attacked and baseline plots in natural, undisturbed stands—all Mountain projects (n = 45)

Variable	Units	Mean	SD
Slope	%	18.9	11.2
Aspect	degree	153.4	98.7
Surface sand	%	55.1	13.8
Surface silt	%	24.0	8.6
Surface clay	%	21.0	12.5
Surface pH	$\log \frac{1}{[H^+]}$	4.9	0.4
Surface soil depth	cm	18.3	12.1
Subsoil sand	%	46.3	15.9
Subsoil silt	%	22.4	8.7
Subsoil clay	%	31.2	13.7
Subsoil pH	$\log \frac{1}{[H^+]}$	5.1	0.3
Pine BA	ft^2/acre	98	31.8
Hdwd. BA	ft^2/acre	34	20.1
Total BA	ft^2/acre	132	34.2
Understory	%	43	35.1
Age	years	57	17.2
Density—all stems	trees/acre	712	551.6
Density—stems >4.6 inches d.b.h.	trees/acre	255	107.7
Site index at 50 yrs	ft	72.9	14.3
Avg. bark—fissure	in	0.4	0.2
Avg. bark—ridge	in	0.9	0.2
Avg. radial growth 0–5 yrs ago	mm	9.4	4.5
Avg. radial growth 6–10 yrs ago	mm	9.3	3.6
Avg. stand d.b.h.—pine	in	7.5	3.5
Avg. height—pine	ft	55.2	18.3
Live crown ratio	%	36.5	10.9
Total stand volume—pine[1]	ft^3/acre	2162.2	967.4
Total sawtimber volume—pine[2]	ft^3/acre	1309.1	1008.4

[1]Volume in pine trees with d.b.h. $\geqq$4.6 in.
[2]Volume in pine trees with d.b.h. $\geqq$9.6 in.
Volume equation (MacKinney and Chaiken 1939):

$$\log_{10}(ft^3 \text{ volume}) = 1.9557 (\log_{10} \text{d.b.h.}) + 1.0971 (\log_{10} \text{total ht.}) - 2.8209$$

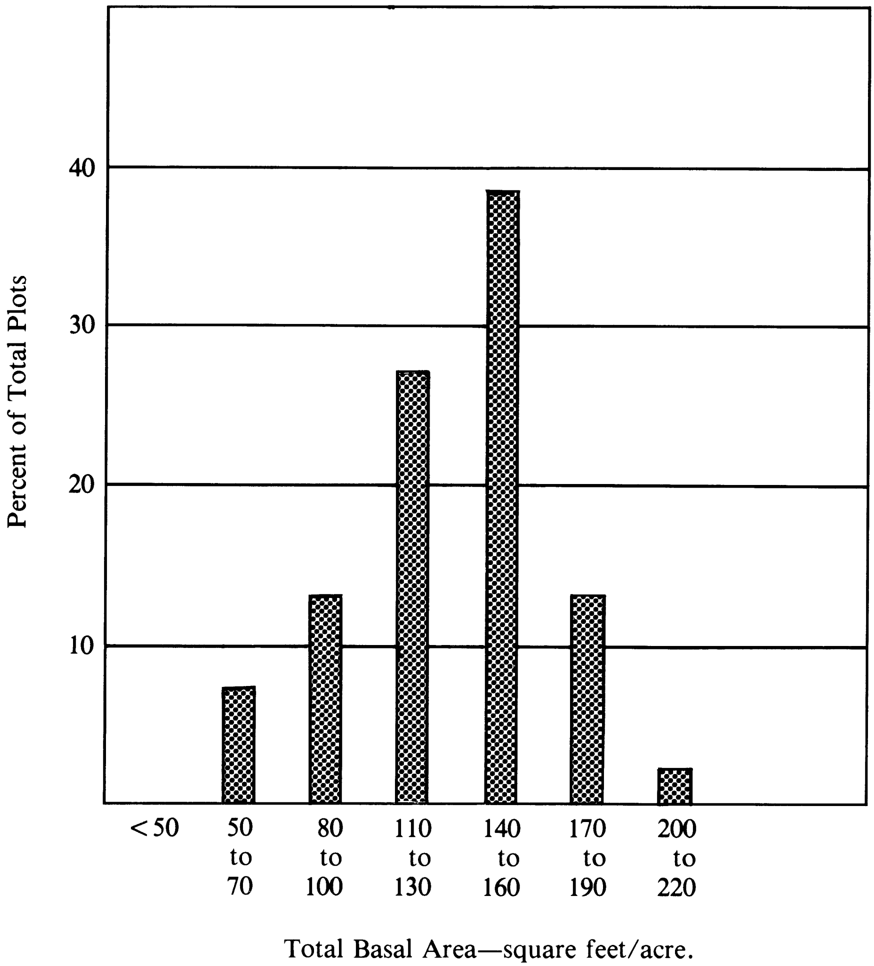


Figure 17.—Distribution of natural, undisturbed Mountain stands by basal area classification.

Table 66.—Landform classification of attacked plots in natural, undisturbed stands—all Mountain projects (n= 45)

Landform	Attacked
	Percent
1. Flood plain	0
2. Stream terrace	0
3. Bench	2
4. Cove/colluvial toeslopes	10
5. Northerly aspect slopes — <2500 ft	25
6. Northerly aspect slopes — 2500-4500 ft	0
7. Northerly aspect slopes — >4500 ft	0
8. Southerly aspect slopes — <2500 ft	27
9. Southerly aspect slopes — 2500-4500 ft	27
10. Southerly aspect slopes — >4500 ft	0
11. Ridge and upper slope — <2500 ft	7
12. Ridge and upper slope — 2500-4500 ft	2
13. Ridge and upper slope — >4500 ft	0
	100

Table 66 shows the distribution of Mountain infestations by landform classification. Since there is no comparative baseline data, conclusions as to landform susceptibility are speculative; but 72 percent of the infestations were recorded on southerly aspects and those northerly aspects above 4,500 ft in elevation. Such sites would likely be under more stress during temporary drought conditions. This fact would increase the susceptibility of these landforms above others. In fact, 72 percent of the infested Mountain plots had a recorded "water regime" of dry to very droughty (see the *Soil Resources Guide* for water regime definitions [USDA Forest Service 1972]).

Average infestation size was comparable to that in the Coastal Plain and Piedmont; 89 percent were < 1.0 acre in size and 63 percent contained 25 or fewer SPB-killed trees. Only 5 percent of Mountain infestations are >2.25 acres. However, 11 percent of them involved over 100 killed trees, so the severity of attack (as measured by proportion of trees killed) may be greater in the Mountains.

Summary and Conclusions

The rationale for the coordinated data collection procedures was to provide standardized information on a wide range of variables that could be used to detect conditions associated with SPB infestations in the several study areas. The wide variability of climatic, edaphic, physiographic, and biotic factors in southern and southeastern pine forests suggested that variables important in one place may be less so in another. And differences also exist in levels, and kinds, of human activities in these forests.

Nevertheless, some factors were consistently related to SPB activity. Stand stocking level and mean radial growth rate were the most apparent, especially in the Coastal Plain. Basal area per acre of pine at the point of origination of infestations was 1.4 to 1.9 times higher than in the surrounding baseline stands (tables 1, 6, 11, and 20). And as would be expected, the highly stocked stands were generally growing slower, especially during the most recent 5 years (tables 1, 6, 11, and 20).

Stand disturbances were more common in SPB-attacked stands, and the most prevalent factor was lightning. Recent logging activity (less than 1 year old) was also somewhat more common at the point of origination of the infestations. Interestingly, the incidence of beetle infestations was generally reduced in stands that had been logged 1 to 5 years earlier.

In addition to these general relationships, some conditions were peculiar to a geographic subregion, or to an individual project area.

Coastal Plain

This subregion, and especially its West Gulf portion, was the most intensively studied. In the lower areas of Mississippi, Louisiana, and Texas, infestations occurred more often than expected on wet, low-lying sites of higher site index. High volume and BA typify all Coastal Plain infestations. Shortleaf pine was the preferred species in Arkansas, but loblolly pine was preferred elsewhere in the Coastal Plain. In general, stand conditions appear to be more important than site conditions in determining susceptibility in this subregion. Proper stand management practices (e.g., thinning and cull tree removal) would, therefore, reduce the incidence of SPB damage in these stands.

Piedmont

Shortleaf pine stands, with reduced radial growth, were more susceptible to SPB in the Piedmont. In contrast to conditions in the Coastal Plain, site factors appeared to be more related to infestations in the Piedmont. Surface soil depth, soil pH, and eroded heavy clay soils were more important. Though treatments to improve growth rate of pine stands may reduce susceptibility to attack, the importance of site characteristics and the greater susceptibility of shortleaf pine stands are most useful. These facts permit the identification of sites and landforms most likely to be attacked, and these can be more intensively monitored for SPB.

Mountains

The data base for the Mountain subregion was quite limited. In general, though, attacked stands seemed to have relatively high volume and lower-than-normal growth rates. Attacked stands were on sites that would be subject to extreme stress during droughts. In the Georgia Mountains, shortleaf and pitch pines were preferred hosts but Virginia pine, the most abundant pine species in the area, was attacked less frequently than expected.

Clearly, certain site, tree, and stand characteristics are associated with SPB attacks. Some of these relationships have been known for years by "woods-wise" foresters. The ESPBRAP Coordinated Regional Site/Stand Project has quantified these variables in a manner that can be used to develop stand hazard-rating models and management recommendations. The resource manager can begin to do more than simply react to SPB after timber is destroyed. He can manage his lands to lessen the chance of beetle attack in the future.

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Appendix

The data summarized in this publication were used to elucidate associations between SPB outbreaks and conditions in the forest. This understanding is useful in suggesting silvicultural practices to lessen the beetle's destructive impact. The data were also used to develop hazard rating systems that the forester can use to prioritize his pine stands for silvicultural preventative treatments and for surveillance activities. Interpretations of the basic data and its uses in silviculture and in stand rating have been discussed by Hicks (1980), Belanger (1980), and Lorio (1980).

But the data may continue to have use in forest entomology for the validation and refinement of stand rating models as well as for the development of new models using new procedures in statistical ecology. The data should also be of value for some investigations in basic forest ecology and forest inventory.

To provide for future availability, the complete data set has been transferred to computer tape. The complete Coordinated Site/Stand Data file is in card image format and contains three different card types. Card types 1 and 2 describe an individual plot and card 3 describes the individual trees on the plots. The variables on each card type are:

Card Type 1

Study unit	Soil characteristics
State number	Landform
Plot number	Texture
Date	Water regime
Slope	Stand origin
Azimuth	Number of pines
Geographic subregion	Number of hardwoods
Stand disturbances	Stand understory

Card Type 2

Stand age	Total number of SPB trees
Stand density	Total infested area
Average d.b.h.	Forest type
Smallest d.b.h.	Average bark thickness
Largest d.b.h.	Average radial growth
	Spot status

Card Type 3

Species	Height to live crown
Status (live or dead)	Crown class
Disease	Age at b.h.
d.b.h.	Bark thickness
Total height	Radial growth

An unabridged copy of the file on magnetic tapes can be made available to researchers. The tape will have the following characteristics:

1. Unlabelled
2. Unblocked, 80 bytes per record
3. ASCII coded
4. 1600 BPI
5. Odd parity

Researchers who use any of the data in publications should negotiate appropriate recognition with those who collected the data (*see* the Introduction).

For further information on data availability, contact

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